
Pump efficiency and economics 14

14.1 Economic optimisation

- 14.1.1 General
- 14.1.2 Whole-life costs
- 14.1.3 New and existing plant
 - 14.1.3.1 Process adaptation

14.2 Economic assessment criteria

- 14.2.1 Investment calculation - new plant
 - 14.2.1.1 Present capitalised value method
 - 14.2.1.2 Annuity method
- 14.2.2 Investment calculation - existing plant
 - 14.2.2.1 Present capitalised value method
 - 14.2.2.2 Annuity method
 - 14.2.2.3 Pay-off method
 - 14.2.2.4 Investment grant
- 14.2.3 Estimated profits and service life
 - 14.2.3.1 Estimated profits
 - 14.2.3.2 Service life
- 14.2.4 Energy costs

- 14.2.4.1 Tariffs
- 14.2.4.2 Annual energy costs

14.3 Important system characteristics

- 14.3.1 Pumping efficiency
- 14.3.2 Demand variations
- 14.3.3 Availability
 - 14.3.3.1 Liquid transport system
- 14.3.4 Hydraulic power
 - 14.3.4.1 General
 - 14.3.4.2 Static delivery head
 - 14.3.4.3 Pipe flow losses
 - 14.3.4.4 Suspensions

14.4 Partial optimisation

- 14.4.1 Economic pipe diameter
- 14.4.2 Component efficiency
- 14.4.3 Existing plant

14.5 Useful references

14.1 Economic optimisation

14.1.1 General

An important characteristic of pumping plant, from an economic point of view, is its efficiency factor, i.e. the efficiency with which it converts the absorbed energy, usually electrical energy, into hydraulic power. This is especially important, since efficiency factors normally have extremely low values. Reasons for pump efficiency and economic factors are discussed and suggestions for improvement are presented. The secondary costs for the main process, of which the pump unit is a part, can be considerable if factors such as process adaptation and available capacity are not considered when designing the plant. The most precious form of energy in pumping is hydraulic energy, which warrants attention because of the parameters which not only determine the hydraulic power requirements but also the energy consumption.

The basic requirement of every pump installation is to transport liquid. The object of economic optimisation is to enable the liquid conveyance to be carried out at the lowest possible cost. The actual liquid transportation, however, often constitutes a small part of a much larger process. An evaluation of the liquid transport costs must, therefore, also include the costs of adaptation to the main process, or if adaptation is not carried out, the resultant costs of a less effective main process.

Since the required liquid transportation cannot be performed without the contribution of all components in the pumping plant, the complete liquid transportation system should be considered when carrying out economic optimisation. Only when the remaining costs are not affected, can partial optimisations give completely accurate results. Partial optimisations do, however, have the advantage that they are easier to evaluate and are therefore applied extensively, despite the risk of certain errors.

14.1.2 Whole-life costs

The cost which should be minimised is the plant whole-life cost, i.e. the summation of all the costs which occur during the total economic life span of the plant. This begins with planning and drafting and ends when the plant is written off or otherwise disposed of. Whole-life costs are traditionally divided into investment and operating costs.

Investment costs consists of the sum of the following:

- planning
- design and drafting
- equipment
- installation and commissioning
- process adaptation
- staff training
- disposal, writing off

Operating costs consist of the sum of:

- maintenance, parts and labour
- energy consumed

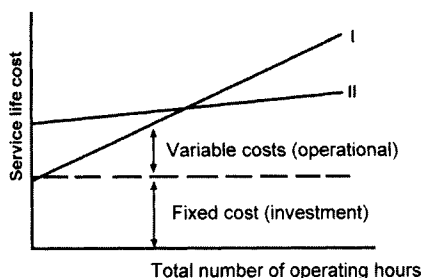


Figure 14.1 Graphical representation of whole-life costs

If the pumping plant is critical to a process and space is not available for stand-by capacity, the cost of lost production can be considered as a running cost.

The investment costs are basically fixed price in character, i.e. in principle they are independent of the extent to which the plant is used. Whereas the operating costs increase with the number of hours of the operation.

The two alternatives in Figure 14.1 show the influence which the number of operating hours has in respect of plant whole-life costs. Plant I, which is characterised by its simple construction with low investment costs, gives the lowest total cost despite its higher operating costs, low system efficiency, when the total number of operating hours is low.

For longer operating times, however, the relatively expensive plant II, with its high efficiency, shows the lowest whole-life cost. In practice, the operating costs will not be linear. As the plant ages, efficiency will be reduced and maintenance costs and spares usage will increase.

The distribution of costs for the various items of expense are naturally different for each case. An example of the items, together with their cost distribution, is shown in Table 14.1. These figures are derived from estimates made within the cellulose and paper industry.

Expense item	Cost %	Cost %
Pumps including mounting	4	
Temporary liquid storage	8	
Electrical equipment	12	
Instrumentation	8	
Pipework	20	
Administration	8	Investment 60 %
Maintenance including operational administration	11	
Energy	29	Operating 40 %
Total	100	100

Table 14.1 Distribution of whole-life costs for a liquid transportation system

According to Table 14.1 therefore, the cost for pumps represents the smallest part of the fixed costs, whilst energy and maintenance are the largest part of the total costs. A doubling of the pump investment costs would only increase the total cost by 4%. A reduction of the pump energy consumption by 25%, which in many cases is quite feasible, would reduce the whole-life costs by as much as 7%. It can also be seen from the Table that energy costs, 29%, together with the investment costs for the pipework, 20%, are the two dominant costs and account for half of the total cost of the system.

Even if the values in Table 14.1 refer to a special branch of industry, similar, but not identical, distribution trends are to be found in many pump installations. It must be remembered that the cellulose and paper industry is characterised by a predominance of stainless steel and super stainless steel pumps. And also that this industry handles very difficult products which result in very robust pumps that suffer particular operational problems. Analysis of other industries has shown the whole-life electrically energy consumption to be between 10 and 20 times the pump purchase cost.

Very small improvements in operating efficiency can return a substantial reduction on overall energy expenditure. Within sewage systems, water supply, heating, ventilation, sanitation and district heating, the cost of pipes and fittings usually show higher values but, together with energy costs, they still constitute the largest items. On the other hand, large engines, steam or gas turbines, will be much more costly than equivalent electric motors and inflate the purchase cost of the pumps. Engines may be much less efficient if waste heat recovery is not implemented. However low efficiency may not be a problem if the fuel cost is very low or "free". For small, simple pumping plant, however, the costs associated with labour and administration

can often predominate. In such cases it is important that the plant is of a simple construction being easy to install and requiring little maintenance.

14.1.3 New and existing plant

The design and layout of new plant offers a greater freedom of choice with respect to economic optimisation than is the case for existing plant. For new plant the conditions are more favourable for total optimisation, since all the plant components can be chosen freely.

14.1.3.1 Process adaptation

Normally, economic optimisation is carried out for a number of technically feasible alternatives. The costs for the various items are determined and summated as in the previous Section. The alternative selected is that which fulfils the liquid transportation requirements whilst incurring the lowest whole-life costs. The opportunities presented by a new plant should be seized upon to achieve good adaptation to the process. Since the major costs are often associated with the main process, of which the liquid transportation is only a part, considerable cost reductions can be achieved by suitably designing the pumping plant.

The following examples are given in order to explain what is meant by the term "process adaptation".

- The transfer of process liquid between two process operations without synchronised flow requirements; the process availability is increased if temporary storage is included in the liquid transportation system.
- The pumping of sewage water to a sewage works regularly; constant flow assists the purification function of the sewage works.
- The pumping of drinking water to a water tower; the matching of supply to consumption results in a smaller water tower.
- The pumping of hazardous liquids; careful selection of the pump size and design of the shaft seals or use of glandless pumps reduces the costs of environmental protection.
- The gentle pumping of food products; reduces product damage and costs.
- The correct choice of low speed pumps for abrasive liquid-solid mixtures; reduces wear, costs of spare parts and labour costs.
- The scheduled adjustment of pump configuration, adding a stage, changing impeller diameter, changing piston/plunger diameter; matching flow/pressure requirements to system changes to reduce energy consumption.

Optimisation of existing plant should also, of course, consider the costs of process adaptation. Here, however, many parameters are already established which imposes limitations. Optimisation of existing plant assumes therefore, a partial optimisation function. The question is then: whether an extra investment can reduce the operating costs sufficiently to make the improvement profitable?

Examples of modifications proposed for existing plant are:

- Replacement of pump; replacement of impeller with larger diameter; reduction of impeller diameter
- Change method of regulation or control
- The addition of temporary liquid storage
- Pipework or system modifications to reduce pressure losses
- The introduction of improved shaft sealing arrangements

All modifications are introduced with the intention of reducing future maintenance and energy costs.

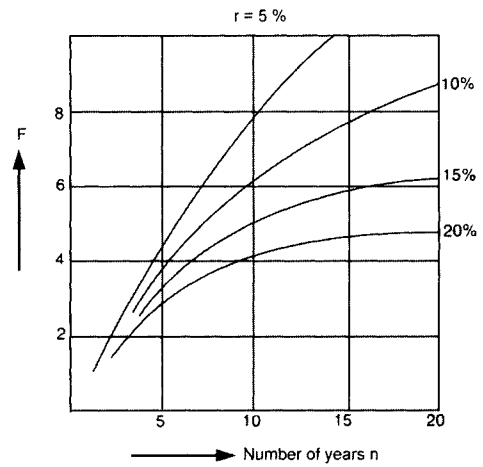


Figure 14.2 Present capitalised value factor

Another type of optimisation occurs when the transportation requirements can be performed by alternative existing pumping units. Such situations appear, for example, in large pipe networks, which are supplied by several pumping stations.

Here since the fixed costs for the plant cannot be changed, the rule is to choose the pump unit which results in the lowest operational costs. The operational costs in these instances are complicated by differing pump efficiencies and varying system pressure losses due to distance and pipe size.

14.2 Economic assessment criteria

14.2.1 Investment calculation - new plant

14.2.1.1 Present capitalised value method

The pumping plant whole-life cost K_L can be calculated as the sum of the investment cost K_i and the capitalised operational costs K_{Dcap} . The operational costs must be paid annually and therefore be summated to a capitalised present value. This is carried out with the aid of a present capitalised value factor F . The whole-life cost becomes:

$$K_L = K_i + K_{Dcap} = K_i + F \cdot K_D \quad \text{Equ 14.1}$$

where:

- K_L = whole-life cost (currency)
- K_i = investment cost (currency)
- K_{Dcap} = capitalised operational cost (currency)
- F = present capitalised value factor
- K_D = annual operating costs (currency/annum)

The present capitalised value factor is calculated from the relationship:

$$F = \frac{1 - (1 + r)^{-n}}{r} \quad \text{Equ 14.2}$$

where:

- F = present capitalised value factor
- r = estimated annual profits (decimal)
- n = number of years

Example:

Two alternative designs of pumping plant have been proposed. Their cost review is as follows:

Investment I = £10,000 annual operational costs = £1,000

Investment II = £7,500 annual operational costs = £1,500

Which plant is preferable from an economic point of view, if the estimated profits are 15% and the service life is 10 years?

If $r = 15\%$ and $n = 10$ years, the present capitalised value factor $F = 5$, from Figure 14.2. Thus:

$$\text{I } K_L = £10000 + 5 \cdot 1000 = £15000$$

$$\text{II } K_L = £7500 + 5 \cdot 1500 = £15000$$

Both plants are similar in this particular instance. If it is probable that the service life will not exceed 10 years, then investment II would normally be preferred since it requires a smaller initial capital investment.

14.2.1.2 Annuity method

For the annuity method the annual plant costs are calculated and minimised. The annual costs consist of the sum of the annuity interest and repayments for a proposed loan which covers the investment cost and the annual operational costs.

$$K = A + K_D = a_F \cdot K_I + K_D \quad \text{Equ 14.3}$$

where:

$$K = \text{annual cost (currency/annum)}$$

$$A = \text{annuity (currency/annum)}$$

$$K_D = \text{annual operating costs (currency/annum)}$$

$$a_F = \text{annuity factor (decimal)}$$

$$K_I = \text{investment (currency)}$$

The annuity factor is identical to the reciprocal of the present capitalised value factor

$$a_F = \frac{1}{F} \quad \text{Equ 14.4}$$

and is determined by service life and estimated profit. Applying this method, for the two investments in the previous example:

$$\text{I } K = \frac{10000}{5} + 1000 + £3000$$

$$\text{II } K = \frac{7500}{5} + 1500 = £3000$$

The two alternatives are equivalent, as before.

14.2.2 Investment calculation - existing plant

14.2.2.1 Present capitalised value method

For existing plant the question is often asked if an improvement of the plant can reduce the operational costs in such a way as to reduce the whole-life costs. According to the present capitalised value method the summation of the savings during the service life will be expressed at today's current value.

$$B_L = K_{Dcap} - K_I = F \cdot K_D - K_I \quad \text{Equ 14.5}$$

where:

$$B_L = \text{total savings during working life (currency)}$$

$$K_{Dcap} = \text{capitalised reduction of operating costs (currency)}$$

$$F = \text{present capitalised value factor}$$

$$K_D = \text{annual operating cost reduction (currency/annum)}$$

$$K_I = \text{investment cost (currency)}$$

Example:

By investing £3,000 it is possible to reduce the annual costs for liquid transportation by £1,000? The plant is designed to operate for 15 years and the estimated profits to be a minimum of 15%. How great are the savings during the service life of the plant at today's currency value?

According to Figure 14.2 the present capitalised value factor $F = 5.9$ for $n = 15$ years and $r = 15\%$.

$$B_L = 5.9 \cdot 1,000 - 3,000 = £2,900$$

Over and above the repayment of investment, including estimated profits, an extra £2,900 is obtained.

If several alternatives exist to achieve a similar technical improvement, then it is normal to choose the alternative which produces the greatest savings.

14.2.2.2 Annuity method

The annuity method answers the question: How great the first year's saving will be at today's currency value?

$$B = K_D - A = K_D - a_F \cdot K_I = K_D - \frac{K_I}{F} \quad \text{Equ 14.6}$$

where:

$$B = \text{annual saving (currency/annum)}$$

$$K_D = \text{annual operating cost reduction (currency/annum)}$$

$$A = \text{annuity (currency/annum)}$$

$$a_F = \text{annuity factor}$$

$$K_I = \text{investment cost}$$

$$F = \text{present capitalised value factor (currency)}$$

Using the values from the previous example,

$$B = 1000 - \frac{3000}{5.9} = £492$$

For otherwise similar alternatives, the size of the annual saving is decisive when making the selection.

14.2.2.3 Pay-off method

The pay-off method uses an imaginary "repayment time" defined by the relationship:

$$T_p = \frac{K_I}{K_D} \quad \text{Equ 14.7}$$

where:

$$T_p = \text{pay-off time (decimal)}$$

$$K_I = \text{investment cost (currency)}$$

$$K_D = \text{annual operating cost reduction (currency/annum)}$$

The shorter the pay-off time the more profitable the investment. By comparing with equation 14.5, it is found that

$$\text{for } B_L = 0 \text{ then } T_p = F$$

i.e. the pay-off time and present capitalised value factor have the same numerical value when the total saving is equal to zero.

Using the values from the earlier example

$$T_p = \frac{3000}{1000} = 3 \text{ years}$$

With an estimated profit requirement of 15% and $F = 3$, the actual repayment time, using Figure 14.2, is approximately 4.3 years.

14.2.2.4 Investment grant

Grants for energy saving investments may apply. For up-to-date information it is best to seek the advice of the relevant local or central government authority.

In the UK for example, the most relevant schemes at the moment would seem to be:

Enhanced Capital Allowances (ECA). ECAs enable a business to claim 100% first-year capital allowances on their spending on qualifying plant and machinery. There are three schemes for ECAs:

- Energy-saving plant and machinery

- Low carbon dioxide emission cars and natural gas and hydrogen refuelling infrastructure
- Water conservation plant and machinery

Businesses can write off the whole of the capital cost of their investment in these technologies against their taxable profits of the period during which they make the investment.

This can deliver a helpful cash flow boost and a shortened pay-back period.

The Market Transformation Programme (MTP) is a DEFRA initiative that develops policy strategies for improving the resource efficiency of traded goods and services in the UK.

The MTP quantifies current thinking on how the daily use of products, systems and services impacts on the environment. MTP uses market projections and policy scenarios to explore alternative future developments.

The Energy Saving Trust (EST) was set up by the UK Government following the 1992 Rio Earth Summit and is one of the UK's leading organisations addressing the damaging effects of climate change. The Energy Saving Trust's goal is to achieve the sustainable and efficient use of energy, and to cut carbon dioxide emissions, one of the key contributors to climate change. The Energy Saving Trust is a non-profit organisation funded by the Government and the private sector.

14.2.3 Estimated profits and service life

14.2.3.1 Estimated profits

Profit estimates should, in principle, correspond to the interest on capital which would otherwise be realised from an alternative investment. It is a measure of a company's profitability and is higher than the current bank rate. The profit estimate increases with reduced capital resources, since it is necessary to be more particular when investment capital is limited. Profit estimates are rarely considered at less than 15%.

The methods of calculation previously reviewed assume that the annual operating cost reductions are of the same magnitude from year to year. The majority and largest savings on the operational side are achieved by reducing energy consumption. Energy costs, currency per kWh, can also be expected to rise more quickly than other costs, which means that energy savings will become more profitable with time.

One way of considering energy cost increase when making economic calculations is to use a corrected profit estimation.

$$r_k = r - e + i \quad \text{Equ 14.8}$$

where:

- r_k = corrected profit estimate (percentage)
- r = uncorrected profit estimate (percentage)
- e = rate of increase of energy costs (percentage)
- i = general inflation rate (percentage)

A more rapid rate of increase of energy costs can in this way be transferred to a reduced profit estimation requirement for energy saving investments.

14.2.3.2 Service life

The economic service life is determined by factors such as write-off rules, the technical service life of components and the planned period of use of the plant. As with other parameters for pumping plant, the economic service life is dependent upon the size and type of industry.

As an approximation with the exception of small plant the following applies:

Buildings	40 years
Pipelines, underground	50 years

Other pipelines	20 years
Machines	15 years
Control equipment	10 years
Instrumentation	10 years

The service life of control equipment and instrumentation may be taken as 10 years for financial planning. The rate of change within the electronics industry is very rapid. Control systems and instrumentation should be reviewed every 5 years using the "Present capitalised value" method, to see if improved equipment or improved control strategies could reduce existing operating costs and hence reduce whole-life costs.

14.2.4 Energy costs

Energy costs depend upon the amount of energy consumed, the prevailing energy price scale and fixed costs for the supply installation. Premiums may be levied if the "maximum demand" is exceeded. In the most usual cases of electric motor operation, energy prices are determined by the relevant electricity tariffs.

14.2.4.1 Tariffs

The basis of most forms of tariff is a fixed charge dependent upon the "maximum demand" taken by the consumer and designed to cover:

- The costs dependent upon maximum load, e.g. interest and depreciation of generating plant, rates, taxes, insurance, salaries
- The costs incurred for each consumer, e.g. transformers, meters, meter reading labour, service cabling. And a running charge depending on the energy supplied, e.g. fuel, losses and maintenance of the supply plant, equipment, etc.

For industrial consumption two-part tariffs are common with the fixed charge proportional to maximum kW or maximum kVA demand; and a running cost, kWh, which may be dependent upon the time of day and/or year, i.e. peak and off-peak periods, and also include, for example, a fuel cost variation clause. A kVA maximum demand is preferable since it takes into account the effect of low power factor. It involves, however, more expensive metering equipment. The cost of metering maximum demand makes it uneconomic, in any case, for loads of less than 20 to 50 kW.

If supplies are taken at a high voltage instead of the usual lower voltage for distribution, the maximum demand charge may be less since the consumer then has the option to provide his own transformer.

14.2.4.2 Annual energy costs

The energy costs are a product of energy consumption and cost per unit. The annual energy cost will thus be:

$$K_E = k_e \cdot E \quad \text{Equ 14.9}$$

where:

- K_E = annual energy cost (currency)
- k_e = energy cost (currency per unit)
- E = annual energy consumption (units)

or capitalised for the service life of the pumping plant

$$K_{Ecap} = F \cdot k_e \cdot E \quad \text{Equ 14.10}$$

Chapters 6 and 10 discussed power recovery turbines and engines and gas turbines using local fuel supplies. Every energy supply has a cost. In the case of high pressure liquid, which is supplied to power recovery turbines, the pipework and the control valves will have fixed and running costs. The same type of costs will apply to waste process steam. Local fuel supplies, such as crude oil or LNG, will have a value either as refining

stock or sale to a consumer. These costs must be considered when evaluating the potential of site energy supplies.

14.3 Important system characteristics

14.3.1 Pumping efficiency

The cost of energy is the dominant cost item in most pumping plants. Energy, for which the pump user must pay, is the quantity measured by the electrical supplier or equivalent. The annual energy consumption consists of the product of the power used and the period of actual power consumption. See equation 14.9 for constant load applications and equation 14.11 for variable load applications.

$$E = \int_0^{t_0} P \cdot dt = \sum_0^{t_0} P \cdot \Delta t = P_m \cdot t_0 \quad \text{Equ 14.11}$$

where:

- E = annual energy consumption (kWh/annum)
- P = actual power used (kW)
- t = time (hours)
- P_m = mean annual power used (kW)
- t_0 = operational hours (hours/annum)

The power used depends partly upon the useful hydraulic power required to maintain the necessary flow in the pipe and upon the efficiency of converting the electrical power, or equivalent, into useful hydraulic power. This efficiency is called the pumping efficiency factor and is defined as:

$$\eta_E = \frac{P_h}{P} = \eta_r \cdot \eta_p \cdot \eta_{tr} \cdot \eta_m \cdot \eta_{others} \quad \text{Equ 14.12}$$

where:

- η_E = pumping efficiency factor (decimal)
- P_h = required hydraulic power (kW)
- P = power absorbed (kW)
- η_r = flow regulation efficiency (decimal)
- η_p = pump efficiency (decimal)
- η_{tr} = drive train efficiency (decimal)
- η_m = motor efficiency (decimal)
- η_{others} = other component efficiencies (decimal)

The flow regulation efficiency illustrated in Figure 14.3 takes into account the power losses which are caused as a direct result of the method of flow regulation. Such power losses are caused by throttle regulation in the discharge pipe, by-pass control and on-off or load-unload control.

The expression for regulation efficiency for on-off control consists of the quotient of energy requirements. Whereas the others are represented by the quotient of power requirements.

The pumping efficiency will obviously be determined for the actual operating point and not the rated duty point efficiency, maximum flow point or any other arbitrary operational point. The power absorbed by auxiliary systems; lube oil, seal oil, cooling water; must be included in the overall pump efficiency.

The drive train efficiency represents losses in gears, couplings and speed variators. It is important to consider the transmission efficiency when speed regulation is used. Losses in rectifiers, frequency converters, regulation resistances, additional motor losses, etc., i.e. losses when utilising electrical methods of speed regulation, are traditionally calculated as transmission losses.

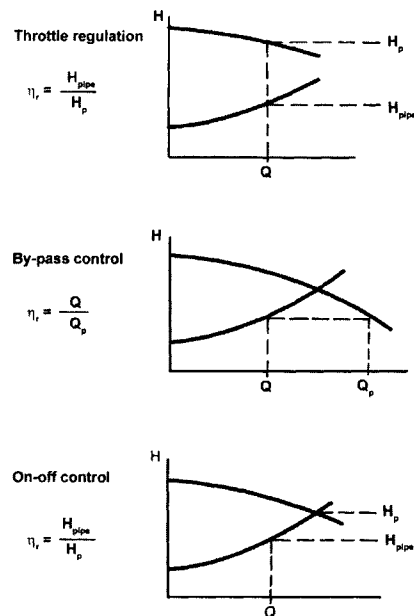


Figure 14.3 Flow regulation efficiency

The motor efficiency should be taken at the actual operating point. A common misconception is to assume that the motor efficiency is still high even at part load. At part load the percentage of reactive power is increased, this may be costed as a separate item. Do not forget about the power absorbed by separately driven cooling fans; this is an integral part of the motor efficiency.

The efficiency of other components takes into consideration losses for phase compensation and protection against supply disturbances, power requirements for supplementary ventilation and other environmental power consuming arrangements which can be directly associated with energy conversion in the pumping plant when working.

It is extremely important to remember that it is the pumping efficiency factor and not the efficiency of isolated components which is the characteristic unit for energy conversion efficiency. If all the component efficiencies are high at the actual operating point then a high pumping efficiency factor will obviously be obtained. However, it only requires one of the component efficiencies to be low to cause a poor total pumping efficiency.

Example:

Determine the pumping efficiency factor for a flow of 70% of maximum flow for the installation shown in Figure 14.4, for (I) speed regulation and (II) throttle regulation.

Using values from Table 14.2:

Case I		Case II	
$\eta_r = 1$	(from Figure 14.3)	$\eta_r = 0.44$	(from Figure 14.3)
$\eta_p = 0.75$	(estimated)	$\eta_p = 0.75$	(estimated)
$\eta_{tr} = 0.75$	(estimated)	$\eta_{tr} = 1$	(estimated)
$\eta_m = 0.90$	(estimated)	$\eta_m = 0.90$	(estimated)
$\eta_{others} = 1$	(not included)	$\eta_{others} = 1$	(not included)
$\eta_E = 0.51$		$\eta_E = 0.30$	

Table 14.2 Estimated component efficiency values

The efficiency factor for on-off control becomes evident, if it is assumed, for example, that the pump operates at full flow, 100% flow, for 75 % of the time. During 30% of the time the pump is then at test. In this case higher pipe losses are obtained during the time the pump operates and the efficiency factor becomes:

$$\eta_E = 0.75 \times 1 \times 0.90 \times 0.60 = 0.41$$

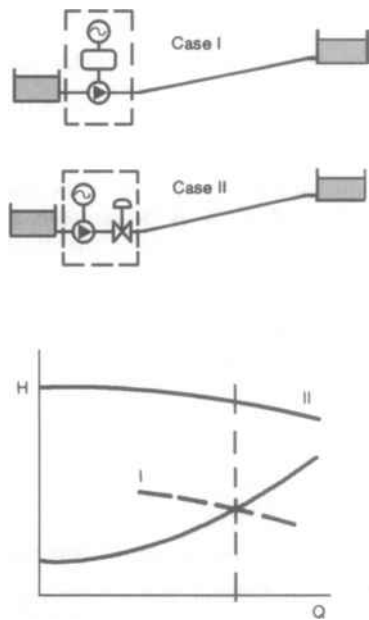


Figure 14.4 Illustration of pumping efficiency factor

For multi-pump systems the efficiency factor can be determined in a similar way. Here, as always, it is only the total efficiency for the actual flow and not the maximum efficiency of individual components which is characteristic for energy conversion efficiency. For on-off control of multi-pump systems there are a number of pertinent operating points. The efficiencies for these flows are greatly influenced by the sizes of the pumps selected.

An example of this is shown in Figure 14.5. In the case of three identical pumps having maximum efficiency at Q_{max} , poor part load efficiencies, shown as circles on the graph, are obtained. By choosing larger pumps, with η_{max} at a somewhat higher Q value, better part load efficiencies can be obtained, shown as crosses on the graph. Only by choosing three different sizes of pump can the highest efficiency be achieved for all three operating points. Three different pumps, however, involve the stocking of additional spare parts and more expensive maintenance. Also the pumps cannot be used as stand-bys for each other.

The basic pumping efficiency is very important. Pump efficiency is greatly influenced by size and choice of pump. Table 14.3 shows typical efficiencies for single stage overhung impeller centrifugal pumps, the most popular rotodynamic pump. Table 14.4 shows typical efficiencies for reciprocating plunger pumps.

Absorbed power kW	Efficiency %
3	37 to 59
7.5	38 to 74
15	50 to 78
30	50 to 79
55	55 to 83
110	60 to 85

Table 14.3 Typical best efficiencies for single stage centrifugal pumps

Absorbed power kW	100% Pressure Efficiency %	50% Pressure Efficiency %	25% Pressure Efficiency %
18.5 to 45	88	76	65
45 to 200	90	78	67
200 to 600	92	80	68
600+	94	84	72

Table 14.4 Typical efficiencies for reciprocating plunger pumps

The efficiency of plunger pumps is closely related to discharge pressure, not speed. Suction pressure does influence the efficiency when high. It can be seen from Tables 14.3 and 14.4 that

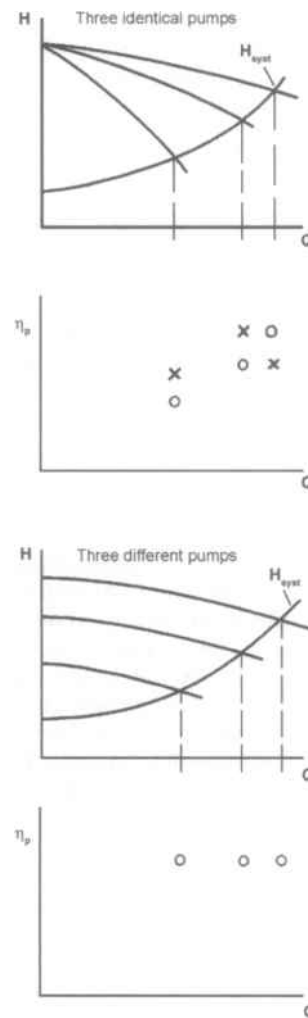


Figure 14.5 Example of pumping efficiency for three pumps connected in parallel

plunger pumps are much more efficient than centrifugal pumps. Reciprocating pumps are more costly than centrifugal pumps from an initial investment point of view, but the running costs can be much lower. Reciprocating pumps can be operated at reduced speeds, without loss of efficiency, to extend the life of parts such as packing and valves.

14.3.2 Demand variations

The primary cause of a low pumping efficiency factor is due to the variation, with respect to time, of the desired flow through the pipes, insufficient consideration having been given to this aspect at the design stage. Normally the mean flow per annum — total supplied volume of liquid divided by a calendar year — is about 10% to 15% of the installed flow capacity Q_{max} . The efficiency factor calculated as a mean efficiency over the year — theoretical hydraulic energy consumption/actual electrical energy consumption — usually gives a value in the region 5% to 40%, which should then be compared with the normal maximum momentary value of 55% to 75%.

The reasons for production or demand variations and the low mean flow are many and some brief examples are as follows:

- Seasonal variations in industry production
- Variations in supply of sewage water
- Variations in quantities of rainfall/snow
- Variations in water consumption
- Variations in heating requirements for central heating
- Component and calculation tolerances
- Margins of safety over and above the normal tolerances

A survey of flow variations with respect to time is a necessary basic requirement for all economic optimisations of liquid transportation. It is desirable that both progressive curves and constancy diagrams are produced.

Modifications for the improvement of the efficiency factor and hence the costs can be of two types:

- To improve the part load efficiency by means of suitable flow control and regulation equipment.
- To reduce extreme flow peaks.

The latter modification involves the addition of a liquid reservoir of some kind in the liquid transport system. Examples of liquid reservoirs are:

- Sumps and reservoirs
- Water towers
- Accumulators

Sumps and reservoirs offer the largest storage volumes at atmospheric pressure. Water towers have limited capacity although they can be substantial. Accumulators are small in comparison, they can be mounted in parallel, but they are the only option for pressures up to 350 bar. Unfortunately, there is no general method for assessing the optimal effect of various modifications and it is necessary to make estimates for each individual case. There is no doubt, however, that considerable cost reductions can be made by improving the degree of demand variation.

14.3.3 Availability

Availability is generally defined by the relationship:

$$A = \frac{MTBF}{MTBF + MTTR} \quad \text{Equ 14.13}$$

where:

A = availability (decimal)

MTBF= Mean Time Between Failures (hours)

MTTR= Mean Time To Restore (hours)

The MTBF should be the summation of operating hours per annum. The MTTR should be the summation of all repair times per annum. MTTR should include all those hours of routine maintenance or adjustment when the pump must be stopped. Another concept frequently overlooked, MTBA, Mean Time Between Adjustments, includes maintenance work performed while the pump is running. MTBA does not affect availability but it does affect running costs.

Centrifugal pumps used within the process industry, for well-ried, normal operating conditions, achieve values of availability in the order of $A = 0.99$ to 0.9999 , i.e. pump shut-down due to pump malfunction is between 1 and 80 hours per annum for continuous operation. These values also include the squirrel cage induction motor but not other electrical equipment. At the other extreme some high pressure water pumps, used for portable cleaning applications, have an availability of 0.88 on a daily basis. Some pumps must have the seals replaced every day.

Availability calculations are applied mainly to multi-pump systems. The percentage of operating time which a given number of pumps in a pumping station can be expected to be available for operation, is calculated from the formula:

$$P = \frac{N!}{K!(N-K)!} (1-A)^K \cdot A^{(N-K)} \quad \text{Equ 14.14}$$

where:

P = system availability (decimal)

N = number of pumps installed (integer)

K = number of pumps unavailable (integer)

A = availability of individual pumps (decimal)

! = factorial ($4! = 24$, $0! = 1$)

All the pumps are thus assumed to have the same availability values. By using equation 14.14 the resultant availability of a pumping station can be calculated and the effect of a stand-by pump can be demonstrated.

Without reserve pump		With reserve pump	
Function requirement	Resultant availability	Function requirement	Resultant availability
1 of 1	0.9900	1 of 2	0.9999
2 of 2	0.9801	2 of 3	0.9997
3 of 3	0.9703	3 of 4	0.9994
4 of 4	0.9606	4 of 5	0.9990
5 of 5	0.9510	5 of 6	0.9985

Table 14.5 Availability of pumping station with and without stand-by pump

From Table 14.5 it can be seen that a pumping station's availability is considerably improved by the installation of a stand-by pump. Function requirement 3 of 4 means that 3 pumps out of 4 will be available for operation. The individual pump availability has been taken as 0.99.

The user must define the availability required, at the inquiry stage, as this parameter has a crucial effect on pump selection. If the user wished to operate for 50 weeks every year the availability would have to be 0.959. If the user wished to operate for 154 weeks and allow two weeks for repair the availability would have to be 0.987. For this type of availability calculation to apply in practice it is necessary to maintain the stand-by pump to ensure that it will operate when required. In cases where it is possible to calculate the cost of a non-functioning pump, for example, in the form of lost production, availability calculations offer a direct economic optimisation possibility. Stand-by pumps usually run a limited number of hours regularly, one week in four say, to ensure the pump is functioning correctly.

14.3.3.1 Liquid transport system

The liquid transport system constitutes a link in a more extensive main process. The design of the system affects the availability of the main process, see Table 13.3 in Chapter 13.. The pipework may be 14 times more likely to create serious problems than a pump. The type of problem posed can be illustrated by a typical practical example. A process consists of two sub-processes for liquid treatment connected by a liquid transport system, see Figure 14.6.

The liquid transport system comprises the connection between the two liquid processes and in Figure 14.6 it can be characterised as a rigid connection. If the sub-process 1 must be shut down because of an internal malfunction, then the liquid transportation and sub-process 2 must also be shut down. The resultant availability for the process will thus be:

$$A = A_1 \cdot A_p \cdot A_2 \quad \text{Equ 14.15}$$

The sub-process can consist of a large number of complicated and sophisticated components and so have a considerably lower availability than the liquid transport system. For this reason it is often unsuitable to make the sub-processes rigidly dependent upon each other.

By introducing a tank into the liquid transport system as in Figure 14.7, it is possible to loosen the connection between the two sub-processes. If the tank is sufficiently large, then the two sub-processes can become totally independent of each other. Sub-process 1 can deliver liquid to the tank while sub-process 2 is being repaired and vice versa. If $A_1 = A_2$ and $A_{p1} = A_{p2}$ the resultant process availability becomes:

$$A = A_1 \cdot A_{p1} = A_2 \cdot A_{p2} \quad \text{Equ 14.16}$$

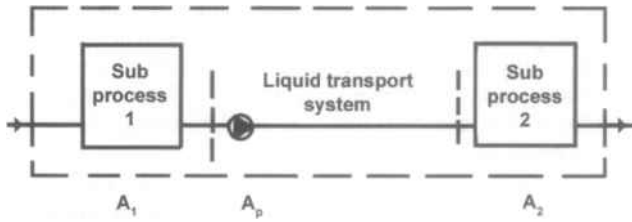


Figure 14.6 Schematic arrangement of a simple liquid system

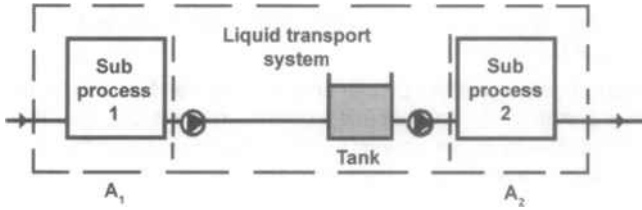


Figure 14.7 Schematic arrangement of a flexible liquid system

The higher value of availability results in a lowering of the mean capacity during operation for the same production.

The required installed capacities of all components in the sub-processes and the liquid transport system are therefore reduced. Lower mean flow also results in lower power and energy consumption if the efficiency of the smaller components is as high as the larger components. These possible cost reductions should be weighed against the investment costs of the tank.

For numerical values of $A_1 = A_2 = 0.90$ and $A_{p1} = A_{p2} = 0.99$ for mean capacity and mean flow during operation, the following results are obtained:

$$\text{without buffer} \quad A = 0.9 \times 0.99 \times 0.9 = 0.802$$

$$\text{with buffer} \quad A = 0.9 \times 0.99 = 0.891$$

With a tank large enough to completely isolate sub-process 1 from sub-process 2 the availability is increased by 11%.

14.3.4 Hydraulic power

14.3.4.1 General

The useful hydraulic power from the pump unit is used to satisfy the pipe system differential head requirements at the actual flow.

$$P_h = \rho \cdot Q \cdot g (H_{\text{stat}} + H_{\text{fpipe}}) \cdot 10^{-3} \text{ (kW)} \quad \text{Equ 14.17}$$

To achieve an optimal economic result, it is important that the hydraulic power is kept as low as possible. A limitation of the required hydraulic power is worthwhile, especially with low pumping efficiency factors of normally 5% to 40%. A reduction of P_h by 1 kW reduces the electric power consumption by 2.5 to 20 kW because of the low efficiency of converting electricity to hydraulic power.

14.3.4.2 Static delivery head

The static delivery head is determined when planning the plant and is often difficult to influence. It should be remembered that for installations where liquid is first pumped up to a tank in order to be subsequently gravity fed to a consumer, the energy required is always greater than if the liquid were pumped direct to the consumer. Such cases should be redesigned, if possible, at the planning stage.

14.3.4.3 Pipe flow losses

The approximate magnitude of pipe friction losses in straight pipes is described by the relationship (assuming a constant friction factor):

$$h_{\text{fpipe}} = \lambda \cdot \frac{l}{d} \cdot \frac{Q^2}{\left[\frac{\pi \cdot d^2}{4} \right]^2} \cdot \frac{1}{2g} \quad \text{Equ 14.18}$$

$$h_{\text{fpipe}} = \frac{\text{constant}}{d^5} \quad \text{Equ 14.19}$$

See also Chapter 3, Section 3.2. The pipe friction losses for a given flow in a 200 mm pipeline are 3.05 times greater than for the same flow in a 250 mm pipeline, i.e. $(250/200)^5 = 3.05$. This calculated example illustrates the importance of correct pipe sizing. Pipe losses are not only friction losses. Pipe fittings, flanges and bends also make a contribution. The selected pipe velocity must take into account the quality of the assembled pipe system and any problems caused by turbulence at poorly aligned connections.

The corresponding expression for losses in valves and fittings, etc., is:

$$h_{\text{fvalves and fittings}} = \frac{\text{constant}}{d^4} \quad \text{Equ 14.20}$$

See also Chapter 3, Section 3.2. Here also there is a large dependence upon size.

For laminar flow:

$$h_{\text{fpipe}} = \text{constant} \times d^{-4}$$

and

$$h_{\text{fvalves and fittings}} \propto \text{constant} \times d^{-3}$$

Demand and production variations lead not only to a low pumping efficiency factor, but also increase the hydraulic power requirement and hydraulic energy consumption. Hydraulic energy consumption is relative to the conversion from pressure to heat, pressure drop, caused by the effects of pipe friction.

For pump installations where $H_{\text{stat}} = 0$, which is assumed here solely for the purpose of simplifying the illustration of the importance of flow variations, then:

$$p_h = r \cdot Q \cdot g \cdot h_{\text{fpipe}} = \text{constant} \cdot Q^3 \quad \text{Equ 14.21}$$

The installed hydraulic power, which is required in a system with mean flow Q_m and demand/production variation $\pm \Delta Q$ is:

$$\begin{aligned} F_h &= \text{constant} \cdot (Q_m + \Delta Q)^3 \\ &= \text{constant} \cdot Q_m^3 \left(1 + \frac{\Delta Q}{Q_m} \right)^3 \\ &= P_{hm} \cdot \left(1 + \frac{\Delta Q}{Q_m} \right)^3 \end{aligned} \quad \text{Equ 14.22}$$

The hydraulic energy consumption becomes dependent upon the shape of the flow demand/supply curve and is illustrated below for three simple special cases.

The hydraulic energy consumption becomes:

$$\begin{aligned} E_h &= \left[1 + 3 \left(\frac{\Delta Q}{Q_m} \right)^2 \right] \cdot P_{hm} \cdot t \quad \text{Square} \\ E_h &= \left[1 + \left(\frac{\Delta Q}{Q_m} \right)^2 \right] \cdot P_{hm} \cdot t \quad \text{Saw tooth} \\ E_h &= \left[1 + \frac{3}{2} \left(\frac{\Delta Q}{Q_m} \right)^2 \right] \cdot P_{hm} \cdot t \quad \text{Sinusoidal} \end{aligned} \quad \text{Equ 14.23}$$

Figure 14.8 and Table 14.6 show that the demand/supply variations have a considerable influence upon both the installed hydraulic power and the energy consumption. From the economic

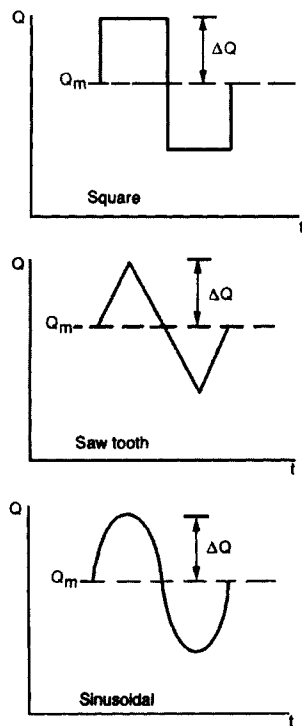


Figure 14.8 Three special cases of demand/supply variations

$\Delta Q/Q_m$	P_N/P_{Nm}	$E_N/P_{Nm} \cdot t$		
		Square	Saw tooth	Sinusoidal
0	1	1	1	1
0.1	1.33	1.03	1.01	1.02
0.2	1.73	1.12	1.04	1.06
0.5	3.37	1.75	1.25	1.38

Table 14.6 Hydraulic installed power and hydraulic energy consumption for different types of demand/supply variation

point of view, reducing the flow peaks and troughs can give good returns.

14.3.4.4 Suspensions

In the case of suspensions and liquid-solid mixtures, yet another variable must be considered, namely the solids concentration. The adaptation of the quantity of solid material transported per unit of time can be made by varying the flow, changing the concentration or a combination of both. Valve regulation is not usually suitable because of the risk of blockage and high wear rates. Other feasible alternatives are illustrated by the example in Figure 14.9.

Referring to Figure 14.9, at nominal capacity, operating point A at 65% centrifugal pump flow, a certain quantity of solid material

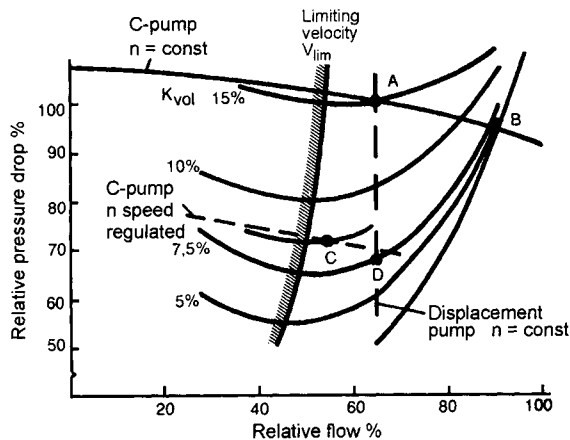


Figure 14.9 Approximate effects of pumping heterogeneous suspensions with nominal capacity, A, and at half capacity solid flow at B, C and D

is transported through the pipeline. The relative required hydraulic power is set at point A as being equal to unity. It is desired to reduce the quantity of solid material per unit time to approximately half the nominal capacity. For a constant speed centrifugal pump this can be carried out by reducing the volume concentration K_{vol} .

The liquid flow increases simultaneously and the relative hydraulic power becomes approximately 1.3 at point B. The liquid velocity increases because the pressure loss through the pipe reduces as the solids concentration is reduced, see Chapter 3, Section 3.3. In the case of a speed regulated centrifugal pump the operating point C is obtained with relative power requirement of 0.6.

Alternatively, a positive displacement pump can be used for the transportation. At half capacity, operating point D is obtained with relative hydraulic power 0.7. The original power of the positive displacement may have been less due to better pump efficiency.

The risk of unstable operation and blockage of the pipe is also illustrated by Figure 14.9. The centrifugal pump curve can maintain equilibrium with the pipe loss curve at two points, at which the operating point at the lower flow leads to blockage in the pipeline. Since the curves intersect each other at nearly the same angle then the risk of instability is relatively great. Corresponding risks do not occur when using a positive displacement pump. The actual power consumption can only be confirmed by evaluating complete pump data.

Considering positive displacement pumps for long pipeline applications introduces yet another variable, the number of pumping stations. Positive displacement pumps can produce high pressures without high speeds or high liquid velocities. The pipe friction losses can consequently be higher before the mixture must be re-pressurised. Positive displacement pumps can handle solid mixtures up to 70% by weight. Pump efficiency is not necessarily a function of solids concentration.

14.4 Partial optimisation

14.4.1 Economic pipe diameter

The two major costs for many pumping plants are the costs of pipelines on the investment side and the energy costs on the operational side. The investment costs increase with increased pipe diameter whilst at the same time operational costs decrease, see Figure 14.10.

The total costs curve represents a minimum for a certain pipe diameter. As indicated in the Figure the shape of the total costs curve is such that it rises more rapidly with reduced diameter, to the left of the economic diameter, than in cases of increased diameter, to the right of the optimum value. In cases of doubt, choose the one having the largest pipe diameter from the feasible alternatives.

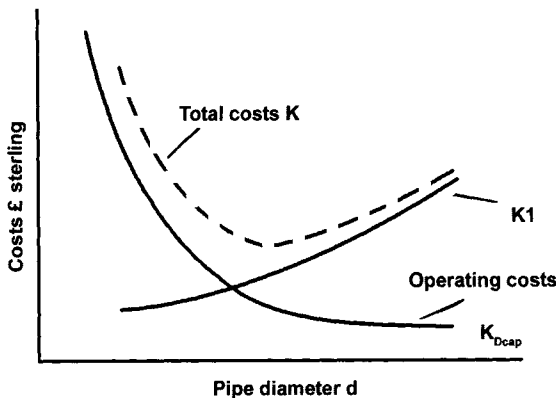


Figure 14.10 Effects on costs of pipe diameter

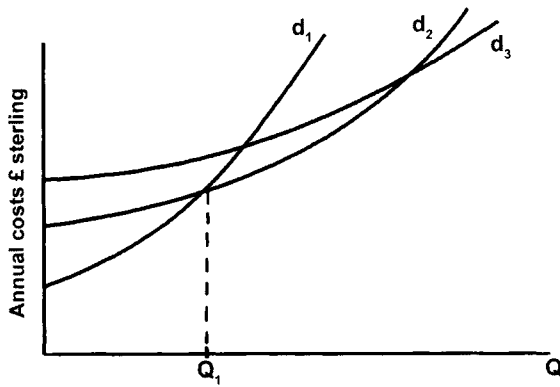


Figure 14.11 Annual costs for a pumping plant using various pipe diameters

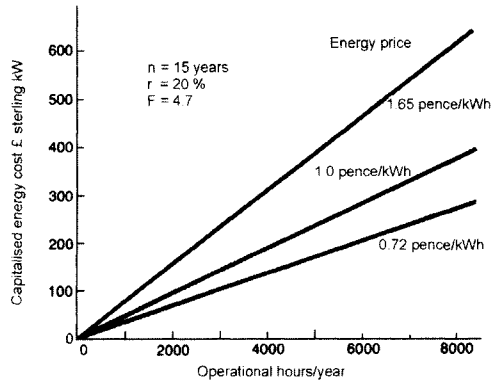


Figure 14.12 Capitalised value in £ sterling/kWh for a reduction of the mean annual electric power used

By calculating the total costs for a number of different pipe diameters it is possible to establish the most economic pipe diameter, see Figure 14.11. The economic diameter varies for different situations. Short operating periods and costly pipe sections, for example, stainless steel, tend to reduce the economic pipe diameter and to increase the economic flow velocity.

By carrying out a partial optimisation, i.e. if it is assumed that all costs are independent of the pipe diameter except for the costs of the pipeline and energy, the following relationship is obtained:

$$Q_1 = \sqrt[3]{\frac{k_2 - k_1}{1/d_1^5 - 1/d_2^5} \cdot \frac{\eta_E \cdot \pi^2 \cdot a_F \cdot 10^3}{8 \cdot \rho \cdot \lambda \cdot t \cdot k_e}} \quad \text{Equ 14.24}$$

where:

- Q_1 = the mean flow for which pipe diameters d_1 and d_2 give the same annual cost (m^3/h)
- k = cost/m of pipeline (currency/m)
- d = pipe diameter (m)
- η_E = pumping efficiency factor (decimal)
- a_F = annuity factor (decimal)
- ρ = liquid density (kg/m^3)
- λ = pipeline loss co-efficient
- t = operating time per year (hour/annum)
- k_e = cost of energy (currency/kWh)

For this Q_1 value the total energy costs are the same. If the mean annual flow for the plant is greater than Q_1 then it is economically feasible to choose pipe diameter d_2 . If Q_m is much greater than Q_1 then the procedure must be repeated using diameters d_2 and d_3 .

The procedure for valves and other fittings is carried out in a similar manner:

$$Q_1 = \sqrt[3]{\frac{k_2 - k_1}{1/d_1^4 - 1/d_2^4} \cdot \frac{\eta_E \cdot \pi^2 \cdot a_F \cdot 10^3}{8 \cdot \rho \cdot \zeta \cdot t \cdot k_e}} \quad \text{Equ 14.25}$$

where:

- k = valve cost including connectors for pipe diameter d

It should be noted that an improved pumping efficiency factor tends to reduce the economic pipe diameter.

14.4.2 Component efficiency

When purchasing new equipment, it is often possible to choose between a cheap pump having low efficiency and an expensive pump with high efficiency. The comparative costs for the two alternatives are:

$$P_{1m} \cdot t \cdot k_e \cdot F + K_{11} \Leftrightarrow P_{2m} \cdot t \cdot k_e \cdot F + K_{12} \quad \text{Equ 14.26}$$

where:

- P_m = consumed mean electrical power (kW)
- t = operating hours per year (hours/annum)
- k_e = energy cost (currency/kWh)
- F = present capitalised value factor
- K_i = investment cost (currency)

It is important to remember that the energy costs are debited according to readings taken from the electricity meter and not from the pump shaft. Because of cable losses, the electric power used is always greater than the pump shaft power. The capitalised value of 1 kW mean electric power is $t \cdot k_e \cdot F$. See Figure 14.12.

The efficiency of other components can be tested in the same way. Conversion to electrical power used must always be made, however. The closer the power consumption lies to the useful hydraulic power in the conversion chain, the greater the energy saving and the greater the motivation for additional investment.

14.4.3 Existing plant

In the case of existing plant there are certain limitations to energy saving possibilities. Changes to the layout and pipework are often difficult to make. Possible improvements are replacements or the addition of supplementary components which do not require too great a disturbance to the plant.

All reductions of the hydraulic power, by means of improvements which reduce the static differential head or pressure drop, in the case of throttle-regulated plant, only result in a greater pressure drop across the control valve and are thus worthless from an energy conservation point of view. To realise a saving of energy some form of improvement must also be carried out on the pump side. For speed-regulated plant all pressure reductions are automatically used.

When planning a project, at the time of determining pump specifications, it is often the case that not all of the plant details are known. It is not therefore unnatural to choose pump sizes with a certain safety margin "to be on the safe side". For this reason many pumps are oversized and result, if adjustments are not made, in unnecessarily high energy costs.

In the case of basic oversizing, the following corrections to the pump may be considered:

- Machining the pump impeller
- Fitting a smaller or larger piston/plunger
- De-staging a multi-stage pump
- Fitting a smaller motor

- Changing the gear ratio of a gearbox

It may also be advantageous to review the connected process(es) to optimise or de-bottleneck and use the excess flow or pressure.

A more common reason for unnecessarily high energy costs is, however, demand/supply variations. In which case the above improvements cannot be applied.

Attention should instead be directed to corrections such as:

- Energy efficient methods of control, the most usual being speed regulation
- Energy efficient methods of control together with reduction of pressure drop and reduced flow peaks and troughs.

The fact that energy conservation proposals and suggestions cannot be realised in practice unless adaptation is carried out on the pumping side, is a strong argument for speed regulation or some other form of energy efficient method of control. Since the investment costs for the pump unit are usually a small proportion of the energy costs, the addition of energy conservation equipment is nearly always profitable. The secondary costs of

an oversized pump are of a very limited nature when using energy conservation methods of control and the excess pump capacity can be considered as a reserve in the event of possible future production increases.

Insufficient engineering hours are used when designing a project to fully assess the economic implications of pump and associated equipment selection. The use of approximate operating data to select equipment always results in inefficient utilisation.

14.5 Useful references

Enhanced Capital Allowances (ECA), DEFRA, 6/H15, Ashdown House, 123 Victoria Street, London SW1E 6DE UK, Tel: 020 7082 8709, Fax: 020 7082 8708.

The Market Transformation Programme (MTP), Future Energy Solutions, PO Box 222, Didcot, OX11 0WZ UK, Tel: 0845 600 895, www.mtprog.com.

The Energy Saving Trust (EST), 21 Dartmouth Street, London SW1H 9BP UK Tel: 020 7222 0101, Fax: 020 7654 2460, www.est.org.uk.

Pump selection

15

15.1 General operating conditions

15.1.1 Liquid properties and operating conditions

15.2 Selection of pump according to duty and capabilities

15.3 Selection of pump according to hydraulic performance

15.3.1 Pumps for low viscosity liquids

15.3.2 Pumps for viscous liquids

15.3.3 Pumps for highly viscous liquids

15.4 Pumps for liquid-solid mixtures

15.4.1 Pumping non-abrasive solids

15.4.2 Pumping abrasive solids

15.4.3 "Gentle" pumping

15.4.4 Pumping waste water, sewage

15.5 Check lists for pump purchase specification

Liquid properties

Solids properties

Pump capacity

Pump, mechanical requirements

Shaft seal

Material

Pipes and pipe connections

Drivers

Electric motor

Engine

Turbine

Drive train

Couplings

Gearbox

Vee-belts

Ancillary equipment

Environment

Erection and installation

Maintenance

Quality Assurance

Purchase conditions

15.6 Purchasing

15.1 General operating conditions

Everything about a pumping application is important. Prospective purchasers should not make value judgements on what is important and what is unimportant. All the important data which is missing or is incorrect will devalue the manufacturer's warranty. The manufacturer's warranty is given for specified operating conditions; undocumented operating conditions are not guaranteed. Operating conditions and corrosion may be experienced while the pump is stationary. Standby equipment may experience a more severe "environment" than the operating equipment.

Engineers completing or filling in data sheets sometimes read too much into the question. Data sheets request "Discharge pressure"; the data sheet does not say "All pressures up to and including". The range of operating variables is critically important. Concentrating on "maximums" is a mistake; the full range of values is important.

15.1.1 Liquid properties and operating conditions

For pump selection for an application, the following information must be known:

- Flow
- Temperature
- Viscosity
- Suction pressure
- NPSHa/NPIPa
- Differential head or pressure
- Discharge pressure
- Constituents in the liquid
- The properties of the liquid

Constituents in the liquid, in this context, mean solids, gases and other liquids. Pumps selected for clean liquids may only last 20% of the time predicted if abrasive solids are present. Entrained gases may reduce the effective NPSHa/NPIPa by over 3.5 m; pumps do not always have a long life. Liquids as trace elements can have a serious impact on the corrosion properties of the bulk liquid.

The properties of the liquid are of critical importance for selecting the correct type of pump. The first obvious property is the vapour pressure. The liquid temperature plus the vapour pressure plus the suction system arrangement provide the NPSHa and the NPIPa. The liquid density varies with temperature; this will affect the conversion to pressure in rotodynamic pumps. The liquid viscosity varies considerably with temperature. Perhaps the liquid is non-Newtonian, a pulp or emulsion. If the liquid is extremely hazardous, then a pump which cannot leak may be required. The corrosive properties of the liquid may be important for the type of pump. Normally, liquid corrosion would decide the choice of material for the pump. If the pump must be manufactured from a material which cannot be cast or welded, the choice of pump types is severely restricted.

Any variation in the operating conditions must be quantified. For any specific variation, the other conditions must be stated. The duration of expected running must also be specified. Changes in operating conditions are always assumed to be relatively slow; slow enough not to cause instability or surges. Rapid changes in temperature can create distortion; for instance it is possible to crack thick casings due to thermal shock. Any rapid changes in operating conditions must be identified. For pumps running continuously, it is usual to specify the Mean Time Between Failures, MTBF.

Chemical processing and oil refining plants can operate for 25 or 50 weeks without a shut-down. Table 15.1 shows typical operating descriptions which might be useful.

Operation	Description
Continuous	Over 8 hours running in any 24 hour period
Light	3 to 8 hours running in any 24 hour period
Intermittent	Up to 3 hours running in any 24 hour period
Irregular	The pump operates for differing times with various periods of extended rest between operation
Cyclic	The pump operates with a set pattern of rest or unloaded running followed by a period on-load

Table 15.1 Plant operating descriptions

The definitions given in Table 15.1 are very generalised and appear in some standards and specifications. The important factor is whether the equipment warms up fully. If equipment runs long enough for all temperatures to stabilise then it is considered to run "continuously". Small equipment can warm up very quickly. Large equipment may take much longer than 8 hours for all temperatures to stabilise.

More costly, slower equipment can, through higher reliability and availability, pay for itself very quickly from increased plant output.

If starting or stopping the pump results in significant changes to the liquid properties or system conditions, these effects must be clarified. High suction pressure during start-up for example, can create tremendous bearing wear problems. Pumps starting cold, at high viscosity, may not achieve the desired performance. Routine maintenance operations on the pump, such as steam or chemical cleaning, may result in modified material selections.

Variations in flow determine whether the application should be shared by several pumps. The system curve, flow/pressure characteristic, then determines whether the division should be between units of equal or different sizes.

Great variations in the viscosity of the liquid may mean, for example, that a centrifugal pump should be used alternatively with a positive displacement pump in cases of low and high viscosity respectively. A positive displacement pump may be able to cope with the complete viscosity range. Viscosity is extremely important. Some pumps rely on viscosity for lubrication. Other pumps rely on viscosity for sealing. Some pumps are unaffected by viscosity.

Variations in flow demand and the consequential change, or otherwise, of differential head or pressure determine the type of flow regulation to be used. In this context the working time of the pump is of considerable importance. The efficiency of the pump unit, at all its operating conditions must be used to calculate the total energy requirement, kWh/annum. The energy costs for pumping can be as great as the purchase cost of the pump after only a few months of operation. The cost of the energy supply must be considered carefully. Can alternative energy sources be used? Can the energy total be reduced by power recovery?

Flow should also be considered both from the point of view of long term changes and also from short term fluctuations. Different regulation methods, with different initial costs and running efficiencies can be applied depending upon the frequency of the changes.

The effect of system pressure changes on the pump flow may be important. A positive displacement pump can offer almost constant flow over a wide range of pressures. This feature may be important and can simplify flow control methods.

Operating conditions can change as the installation wears, corrodes or fouls. Changes to the pump unit, from as new to progressive ageing may be used to optimise performance at different duty points.

The location of the pump within the site also has a marked influence on the choice. The location determines the NPSHa and NPIPa and evacuation and also whether the pump is of the dry pit, wet pit or submersible type. Requirements for space can also lead to a choice between horizontal and vertical designs. The environment at the installation site may also raise special demands with regard to the driver for the pump.

The size, nature and concentration of any particles are also, of course, important factors. Hard abrasive solids will generally have a much more serious effect on pump life and efficiency than soft, deformable solids like wax. The abrasive properties of hard solids should be quantified by testing. The Miller Number test is used extensively for reciprocating pumps. Wax, however, may coat pipe walls and impeller vanes and progressively choke a pump and its system.

When using positive displacement pumps it is important to know the liquid compressibility. As differential pressures increase, the compressibility becomes more essential to evaluate the volumetric efficiency. Few liquids are less compressible than water. Liquified gases, such as CO₂, can be up to six times more compressible than water with consequential reductions in volumetric efficiency.

The hazards posed by the liquid are an important factor. Hazards to personnel, the site and the environment, and the time period involved, must be considered carefully. The location of the site may influence decisions. An oil production platform in the North Sea must be treated differently to a remote site in the heart of the French countryside. Local installation and statutory regulations may also require specific actions to be implemented. The pump may be situated in a hazardous area caused by potentially explosive gases. Surface temperatures imposed on electrical equipment will apply to mechanical equipment, even if not stated. Pneumatically or hydraulically operated pumps may be necessary.

When selecting pumps for a range of applications for one site, select the pump which is best for the application providing whole-life costs are considered. Selecting the correct pump will optimise efficiency and reduce running costs. The cost of extra spare parts for different machines will be outweighed by the reduced energy consumption and extended running times of appropriate equipment.

The skills of local personnel must also be considered. Most pumps are relatively simple and can be maintained with standard tools using established techniques. Some pumps, and/or drivers, may have complicated systems requiring specialist knowledge. In these cases the costs of factory staff for maintenance must be evaluated.

For choice of pump, the auxiliary systems necessary for the pump should also be taken into consideration. The pump itself must often be provided with protection against dry running, against overheating when running against a closed valve and, in the case of positive displacement pumps, against unintentional throttling in the suction or discharge. In many cases shaft seals require sealing or cooling liquids at the correct pressure and with a guaranteed flow.

Sometimes the properties of the liquid may be uncertain. When this problem arises it is best to discuss the effects of variations on pump performance, and perhaps life and reliability, with pump manufacturers or consultants. Values must be placed on uncertain parameters. If this is left to pump manufacturers, they will choose values which are best for their particular pump. The user must analyse the problem and select safe values for the limits of operation.

Table 15.2 lists some typical important ranges commonly encountered. The Compressibility units in this table show the reduction in unit volume per bar differential pressure.

Parameter	Range
Density	500 to 1700 kg/m ³
Solids content	up to 80% by wt
Solids size	up to 100 mm
Viscosity	0.15 to 20000 cSt
Vapour pressure	negligible to 130 barg
Compressibility	1.96E-7 to 1.95E-5

Table 15.2 Typical liquid, liquid-solid mixture properties

As with liquid properties, operating conditions can be uncertain. Table 15.3 lists typical ranges of operating conditions.

Condition	Range
Temperature	-100 to 350 °C
Suction pressure	0.15 to 140 barg
NPSHa	0.75 m and greater
Discharge pressure	0.25 to 4000 barg
Flow (can be zero in some cases)	0.00000001 to 15000 m ³ /h
Power	0.05 kW to 5 MW

Table 15.3 Typical pump operating conditions

15.2 Selection of pump according to duty and capabilities

Decisive factors for the choice of pump are:

- The properties of the process liquid
- The desired pump performance
- Flow and differential head or pressure
- Certain specific requirements in connection with the pump installation

A suitable pump choice is made when all features and properties most suited to the application are assessed. In some cases, however, it is necessary to accept a choice of pump which is not ideal with respect to all features. Then the choice must be made entirely on the basis of the requirements of the specific case, i.e. a compromise must be reached between technical features such as wear capacity or resistance to corrosion. It is important also to consider the economic effects or the difference in characteristics between rotodynamic pumps and positive displacement pumps.

Centrifugal pumps are the most suitable types for about 80% of all pump requirements. Positive displacement pumps are commonly mistaken for high pressure, small flow and for viscous liquid applications. Some positive displacement pumps can be used to advantage for arduous low pressure applications; pumping sewage and viscous tank bottom sludge with sediment. Table 14.4 in Chapter 14 showed for example, that small plunger pumps running at 25% rated pressure can be more efficient than centrifugal pumps.

Liquid properties such as viscosity, resistance to chemical attack, variations in the rate of the chemical reaction with temperature and contamination are especially important not only for choosing the type of pump but also for the specifications intended to serve as a basis for purchasing. Some chemicals will not react at one temperature but will cause substantial damage if the temperature rises above a certain point. Variations in pH can make what is sometimes a harmless solution into a highly dangerous and corrosive solution. Some pumps may be resistant to chemical compounds over a short period but may be attacked over a long period. This factor is important in cleaning, where a corrosive chemical may be used for a short period to remove foreign matter but would damage the pump if it was left in contact for a long period.

15.3 Selection of pump according to hydraulic performance

When considering viscosity, the limitations given for any pump design are complicated by pump size. Small pumps have higher parasitic losses, lower efficiency, due to friction losses in the small passages. As pump size increases these losses become smaller and less important. Increased viscosity, in rotodynamic pumps, increases the parasitic losses and reduces pump performance and efficiency. As a general rule, a viscosity of 300 cSt is a good bench mark for evaluating viscosity effects. The debilitating effect of viscosity on rotodynamic pumps can be mitigated by running pumps at reduced speed.

In the following Sections it is important to remember that viscosity limitations are not “cast in stone” but indicate areas of concern where the transition from low viscosity to viscous and viscous to highly viscous are blurred.

15.3.1 Pumps for low viscosity liquids

Suitable ranges of operation for flows and differential heads can be indicated on the basis of popular rotodynamic pump availability for different types of pumps for low viscosity liquids according to Figure 15.1.

Double suction axially-split pumps and axial propeller pumps can have flows over 50000 m³/h. Figure 15.2 indicates the flow and discharge pressure capabilities of positive displacement pumps. In some cases it is necessary for the liquid to have certain lubrication properties.

Plunger pumps are shown with a maximum pressure of 2000 barg; pumps are available for pressures up to 10000 barg. Very few applications use pressures over 1000 barg. Performance requirements, purchasing cost, running costs, estimated service life and reliability of operation must be considered when choosing pumps. Rotodynamic pumps of various designs cover nearly 80% of all pump requirements. However, looking at Figures 15.1 and 15.2, for flows from 1 to 100 m³/h, and pres-

ures up to 200 m or 20 barg, there are plenty of pump types to choose from.

In some instances the choice of pump is very simple, based on the duty of a single pump:

- Flow over 2271 m³/h ∴ rotodynamic
- Flow less than 0.001 m³/h ∴ positive displacement
- Differential head over 7000 m ∴ plunger pump

In some special applications there are dedicated designs which almost without exception are the most suitable. Some examples of these are heating, water and sanitation pumps.

With rotodynamic pumps, in certain borderline cases, it is possible to choose between single-stage and multi-stage pumps. An analysis of the efficiency and running costs on the one hand and of operational reliability on the other will provide sufficient grounds for a decision.

The speed of the pump is a factor which is often discussed. In principle the choice should be in favour of a speed sufficiently high to ensure that the NPSHa in the plant, less a suitable margin, is used. Possible fears of a reduction in operational reliability in the case of higher speeds should not be allowed to result in the choice of a lower speed, but rather in better quality and testing requirements when purchasing. Requirements of this kind can refer to critical speeds or bearing life or sealing problems, for example. It should, however, be observed that a higher speed may result in higher noise levels requiring acoustic treatment.

In the borderline cases between rotodynamic and positive displacement pumps the form of the pump characteristics and method of regulation often influence the choice. Both types of pump have their distinct advantages, see Chapter 4 with regard to different pumps designs and characteristics.

A difficult problem for all pumps is the presence of air or gas in the liquid. The effect on the effective vapour pressure must not be overlooked. Rotodynamic pumps suffer from a reduction of efficiency when the gas content on the suction side is in excess

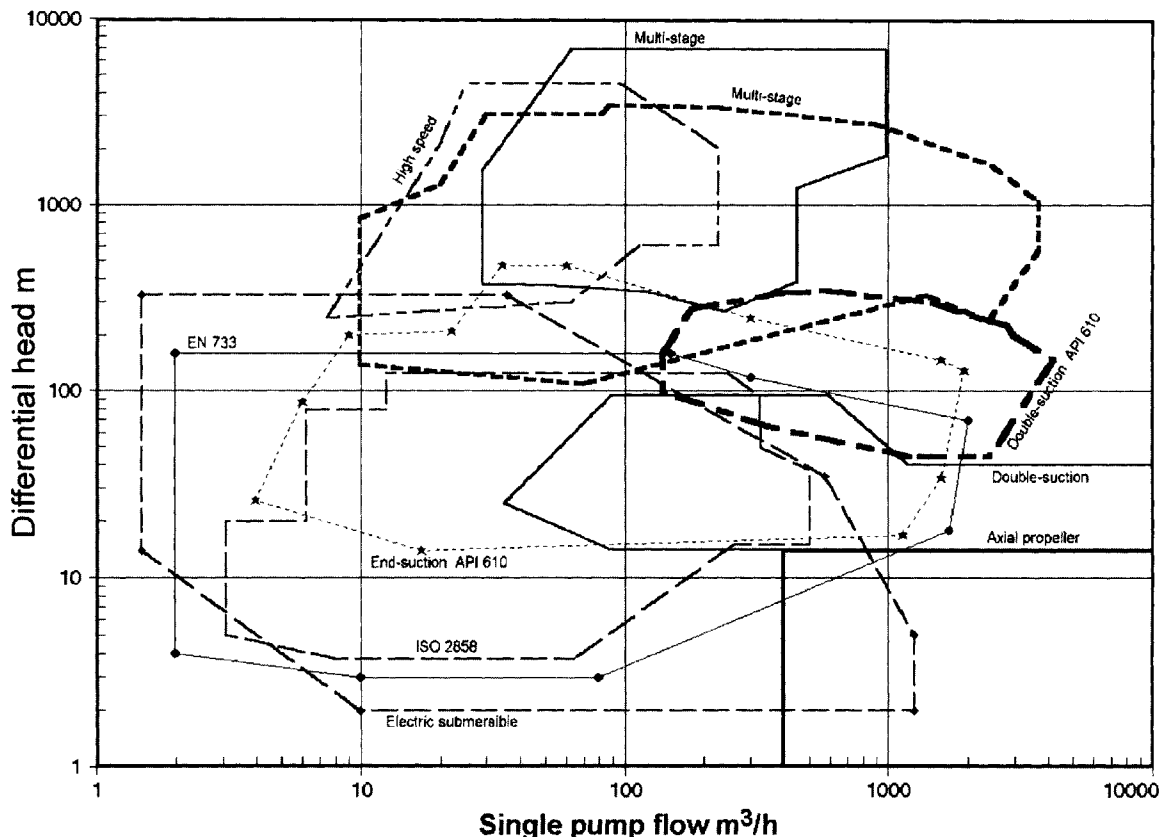


Figure 15.1 Operating ranges of popular rotodynamic pump types

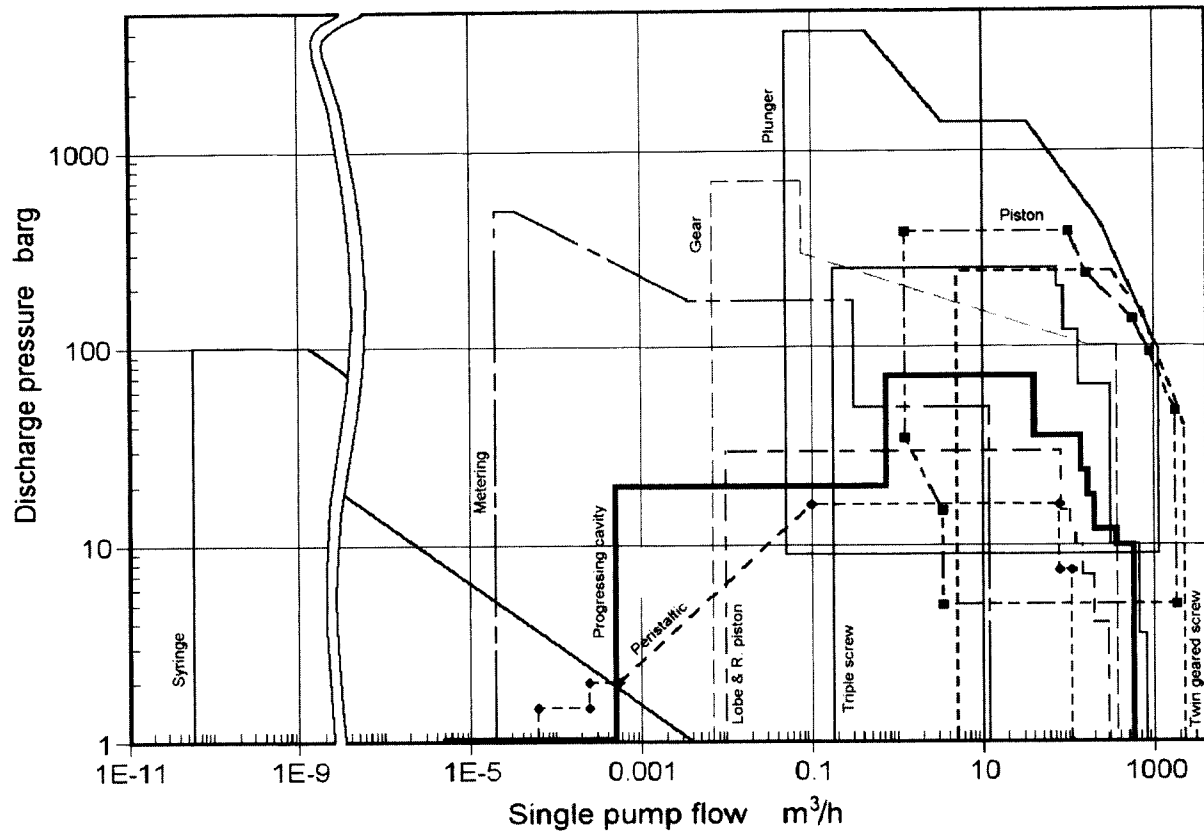


Figure 15.2 Operating ranges of positive displacement pump types

of about 1% by volume. Some rotodynamic pumps, centrifugals for example, can cope with up to 15% without losing prime. Some positive displacement pumps, particularly geared twin screw, can cope with much larger volumes. Dry running must be specified as an operating condition when required. The ability of the pump to handle slugs of gas or liquid must be evaluated.

15.3.2 Pumps for viscous liquids

The viscosity of the liquid can greatly affect the choice of pump. The effect is dependent on the flow and differential head and therefore the size of the pump. The effect of viscosity on the efficiency of centrifugal pumps is shown in Figure 15.3.

The five pumps from A to E are taken from the range outlined by ISO 2858 for end suction centrifugal pumps; F indicates the effects on a very large pump. This data was prepared by using the viscosity correction graphs shown in Figures 4.31 and 4.32. Reduced efficiency leads to increased power consumption which results in higher shaft stresses. It may be the pump shaft stressing which limits viscous operation.

In rotary positive displacement pumps the increase in viscosity reduces slip and improves volumetric efficiency, hence greater flow per revolution. But increased viscosity can also lead to increased fluid friction losses. In triple screw pumps for example, the differential pressure is limited by the viscosity. On one range of pumps, used mainly for lubricating oil duties, the differential pressure capabilities vary from 21/40 bar at 2 cSt to 160 bar at 40 to 200 cSt. The volumetric efficiency improves by about 10% which leads to a slight improvement in mechanical efficiency. Minimum inlet pressure will tend to increase with viscosity.

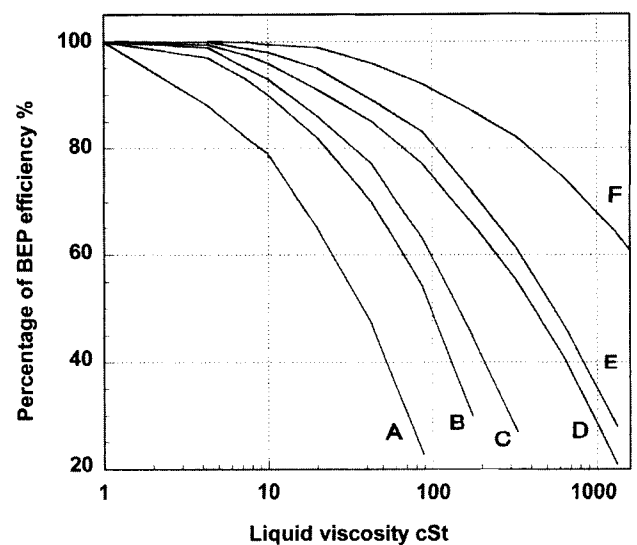
Depending upon the valve design, reciprocating pumps are not affected very much by medium viscosity operation. An increase in NPIPr will be apparent.

Intelligent economic pump selections for viscous liquid operations should be based on whole-life costing. We know that energy consumption is likely to be more important than initial pump cost. Review pump efficiencies at operating conditions to assess actual energy consumption.

15.3.3 Pumps for highly viscous liquids

As has been stated the problems caused by viscosity are related to pump size. In general, for high viscosities only positive displacement pumps are suitable. The choice is then to select the most suitable type.

At high viscosities the NPIPr and MIP will increase. The speed of the positive displacement pump may need to be reduced. When choosing pumps for highly viscous liquids the design of



- (A) BEP duty 2 m³/h at 11 m differential
- (B) BEP duty 11 m³/h at 30 m differential
- (C) BEP duty 25 m³/h at 30 m differential
- (D) BEP duty 110 m³/h at 45 m differential
- (E) BEP duty 225 m³/h at 45 m differential
- (F) BEP duty 2500 m³/h at 185 m differential

Figure 15.3 The viscous effects on efficiency of centrifugal pumps

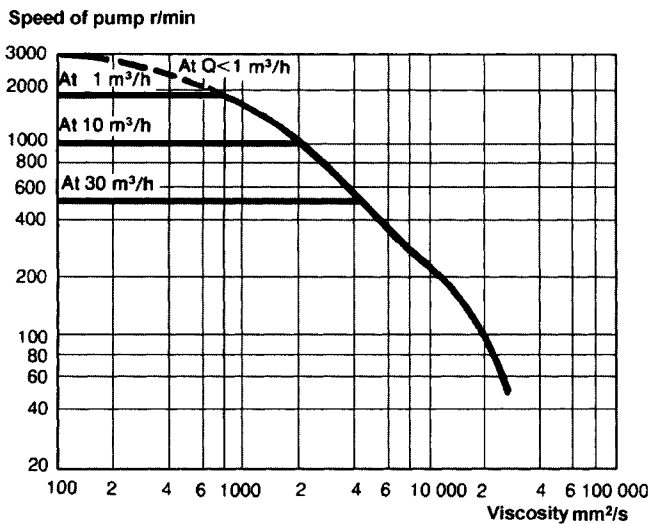


Figure 15.4 Speed of gear pumps for viscous liquids

the suction system must be studied in great detail. NPIPa and MIP must be evaluated very carefully. If the liquid cannot be supplied at the correct flow rate the pump will never function correctly. Severe problems may be experienced on the discharge side of the pump. Large pumps with large connections and low speeds are to be preferred. For extremely viscous liquids, and solids such as wax or lard, feed hoppers and augers may be necessary. Those positive displacement pumps which can handle the maximum pumpable viscosities, approximately 10000 Poise or Stoke, are progressing cavity pumps, lobe and rotary piston pumps and reciprocating plunger/piston pumps.

Figure 15.4 indicates the recommended speed of gear pumps for viscous operation.

Again, ultimate pump choice should be made based on energy consumption and whole-life costs.

15.4 Pumps for liquid-solid mixtures

When pumping solids the distinction must be made between abrasive and non-abrasive solids. The Miller Number test is used for reciprocating pumps. Values below 50 are considered non-abrasive. Review Figure 3.13 in Chapter 3 for the effects of very low concentrations of solids. It is possible to pump solids concentrations up to 70% by weight.

The Miller Number test is conducted using a high chrome cast iron test block. Most pump applications will use a different material. Stauffer, of Escher Wyss, conducted metal tests with a sand-water mixture. The bench mark material was a case-hardened carbon steel. Some interesting data, adjusted for 27Cr iron to be unity is shown in Table 15.4.

Material	Relative abrasion resistance
Hard chrome plate	2.06 / 2.28
Tungsten carbide	1.39 / 4.12
Stellite 6	0.83 / 3.31
Ni-Hard	0.89 / 1.11
27 Cr cast iron	1
13 Cr steel, 441 BHN	0.32
316L stainless steel	0.26
Carbon steel, 195 BHN	0.22
Al bronze	0.13
Ni Al bronze	0.12
Cast iron	0.09

Table 15.4 Relative abrasion resistance to sand in water

There is no consistent method of selecting pumps for solids handling applications. This is because all the pump types which are used rely on different techniques and manufacturers adopt

different philosophies for derating and viscous corrections depending upon their experience.

Centrifugal pumps designed specifically to handle solids react differently to centrifugal pumps designed for clean liquids. This problem is due to the different design methods used. The rheology of the mixture can be a problem; assuming Newtonian behaviour can lead to poor pump selections. Rheology has very serious implications for the pipeline design and predicting the pressure drop.

However, rheology is not a problem to all pump types. Plunger and piston pumps can have the plunger/piston diameter optimised at site after commissioning without too much trouble. The purchaser would have to admit to being uncertain about the Q-H characteristic. The solids concentration can be adjusted to modify the mixture rheology. Chemical additives are also available for the same purpose.

Efficiency and predicted life of wearing parts are the essentials for whole-life costing. The manufacturer should be able to advise the life of any rapidly wearing parts and the Mean Time Between Failures. The time taken to replace rapidly wearing parts is also very important.

15.4.1 Pumping non-abrasive solids

Already, at solids concentrations of 0.5%, the service life of a pump can be severely affected. Liquid-solid mixtures which can be considered as non-abrasive are:

- aragonite (calcium carbonate)
- bauxite
- chalk
- clay
- coal
- gilsonite (natural asphalt)
- gypsum (selenite)
- lignite
- limestone
- mud, drilling
- potash
- rutile (titanium dioxide)
- sewage

The critical element of pump selection is the size of the particles and whether any stringy or fibrous material will be present.

One particular application of non-abrasive pumping is liquid coal fuels. Crushed coal is mixed with water and some trace chemicals to produce a liquid-solid mixture which can be handled by piston pumps. The mixture acts as an emulsion and can be stored for reasonable periods without separation. The liquid coal fuel is pumped from the mine direct to the boiler, usually at a power station to produce electricity, and is injected into the boiler. The solid-liquid mixture is not de-watered. The liquid-solid mixture is a complete fuel.

15.4.2 Pumping abrasive solids

Liquid-solid mixtures which can be considered as abrasive are:

- alundum (Al_2O_3)
- copper concentrate
- fly ash
- iron ore
- limonite (Fe_2O_3)
- microsporite

- magnetite
- phosphate
- pyrites (FeS_2 , CuFeS_2)
- sand
- shale
- serpentine (magnesium silicates)
- tailings
- tar sand

Again the particle size and concentration is critical in pump selection.

Some users have manufactured their own jet pumps. The basic jet pump principle has been adapted in various ways to reduce the effects of wear from the solids. Mine operators seem to be the most versatile in this respect.

15.4.3 “Gentle” pumping

“Gentle” pumping can be redefined as low shear or delicate handling pumping. The process liquid is not subject to surfaces which travel at high velocities. “Gentle” pumping is used when the solids to be transported by the liquid are to be damaged as little as possible or the liquids are not to be emulsified. For this purpose the “products” can be anything from delicate bacteria cultures to foodstuffs, live fish and root crops. (See Chapter 16, Section 16.10 for an example of the pumping of delicate solids.)

The basis for a systematic choice of pump is seldom available. In the case of rotodynamic pumps, the differential head per stage is a measurement of the stirring of the liquid. Front and back shrouds of an impeller create shear in an almost stationary liquid. In order to avoid damage to the transported particles the passages through the pump should be large. This means that among rotodynamic pumps, submersible non-clogging and submersible pumps with standard motor should be used, and among positive displacement pumps in the first instance lobe and rotary piston pumps are of special interest. For higher pressures plunger and piston pumps can be used.

Figure 15.5 shows a comparison between damage to products caused by two different types of non-clogging pump. The figure demonstrates that in this case the channel impeller type pump is superior to the free-flow pump. On the other hand if bacteria cultures are pumped as active sludge in a purification plant other test results indicate that the free-flow pump is clearly superior to the channel impeller type. These examples illustrate the difficulties in a general assessment of the “gentle handling” property.

15.4.4 Pumping waste water, sewage

Low pressure vertical plunger pumps

The properties of the pump must be formulated in terms of the waste water to be pumped. A modern waste water pump must be designed to pump waste water of the consistency found today and likely to be found during the next 10 years. It is possible to grade the water to some extent. The extreme cases range from very rural areas to large city centres. Whatever the scope of a definition of waste water, the following requirements apply:

- Minimum risk of blockage (non-clogging)
- High degree of operational reliability (mechanical)
- Low running costs (energy consumption and service)
- Simple, quick maintenance in the event of breakdown

In recent years the definition self-cleaning, non-clogging, has been used less and less to describe the ideal pump. This was a pump equipped with a through-flow impeller of channel type. Previously this type of pump could be considered, with the waste water of that time, to have satisfied the special require-

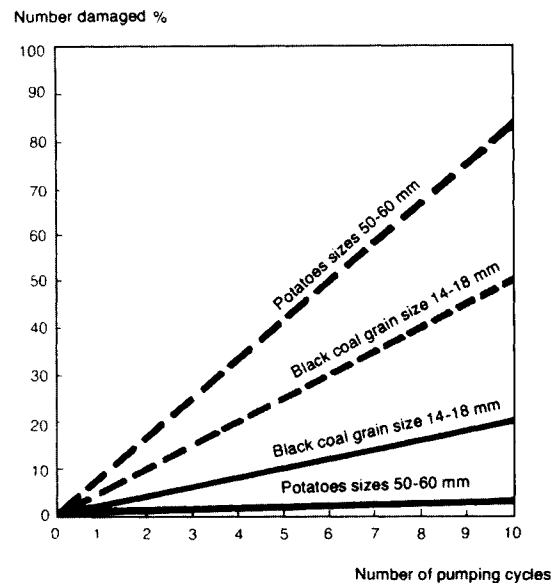


Figure 15.5 Results of pumping tests with a free-flow pump ---- and a channel impeller pump ———. For black coal the damage criterion was when the size of grain was reduced to less than 12 mm

ments for which it was designed. However, the waste water produced today and still more likely, that to be produced in the future, makes it increasingly difficult for pumps with through-flow impellers, channel impellers, to meet the non-clogging requirements.

The dimensions and design of the channels in relation to the type of contaminant found in the liquid are of critical importance to the non-clogging capability of the pump. The design of the cross-sectional area of a channel impeller varies from rectangular to circular. It is not known for certain whether the design of the channel has any real effect on the non-clogging properties of the impeller. A circular through-flow area may be assumed to offer superior characteristics for the pumping of spherical objects than an impeller with a rectangular cross-section. In the case of textile contaminants a rectangular design may be preferable. Available statistics concerning breakdowns due to the blockage of channel impellers give little guidance to the assessment of different designs of impeller, see Figure 15.6.

Impellers for waste water pumps are usually designed with one or two channels. Apart from reasons connected with the hydraulic design, which can dictate different numbers of channels, there is also a lack of reliable assessment of the respective through-flow capacities of one and two channel impellers. In general it may be said that two outlets from the impeller are better than one, provided that the accessible area of each channel is of an acceptable size. The acceptable size of a channel area is of course dependent on the size and character of the contaminants in the waste water.

Certain guide values have established themselves in purchase specifications. Often the area is indicated as corresponding to a spherical through-flow of 75 mm for small pumps and of 100 or 125 mm for larger pumps. In some cases there is a requirement that the through-flow area should be as large as that of the discharge pipe. In such cases it may be advantageous to have suction and discharge connections the same size. The specification of these values probably has its basis in the fact that the magnitude of the H-Q curve in relation to the motor speeds in current use does not allow scope for larger impellers.

The speed of the impeller has a definitive effect on the flow of the through-flow impeller and thereby on the size of the through-flow area. With the aid of the Laws of Affinity, it can be demonstrated that a given pump at a certain speed will, at double the speed, double its flow, the delivery head will increase four times while the power requirement is increased eight times, neglecting all system effects. For pumps with small flow

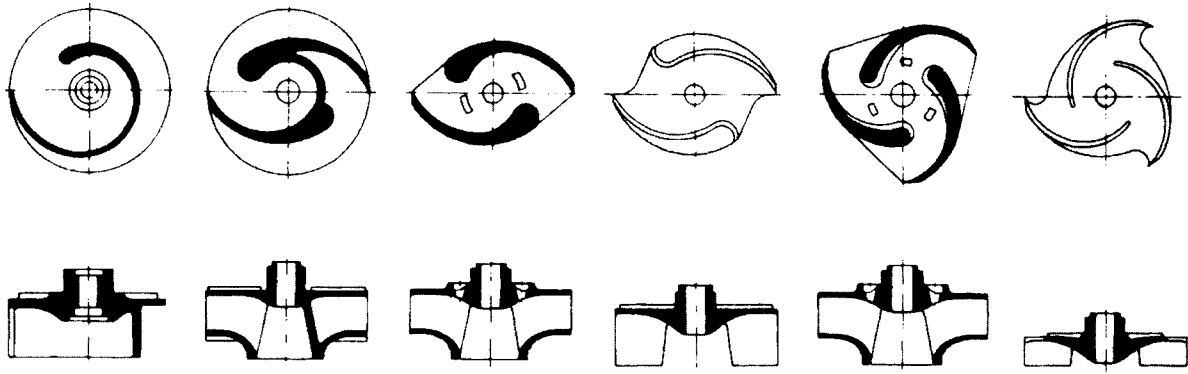


Figure 15.6 Various designs of channel impeller

and moderate pressure the speed must be determined on the basis of the minimum permissible through-flow area. The speed greatly influences the dimensioning of the through-flow area of a through-flow impeller. On the other hand the speed in itself is without significance with regard to the ability of the pump to handle contaminants.

Thanks to the hydraulic design of the interior passages, the flow through a free-flow pump is not dependent on speed. The only function of the impeller is to supply energy to the liquid and it can be dimensioned without regard to the through-flow area. The low symmetrical impeller creates negligible deflection to the shaft. This results in increased service life for shaft seals and bearings.

For normal waste water the free-flow pump may be regarded as non-clogging. The choice of a non-clogging pump represents a compromise between non-clogging properties and energy consumption. On the grounds of experience it may be claimed that free-flow pumps are the best choice up to capacities of about 5 kW and up to about 10 kW at remotely located pumping stations. Travelling costs for cleaning and maintenance greatly affect the optimum. Waste water pump schemes favour submersible high-speed free-flow pumps with capacities of up to 30 kW. In the case of larger pumps, through-flow types will probably continue to dominate the field.

For duties up to 45 m on systems with a large H_{stat} component, a low pressure vertical plunger pump may be better. These pumps run at low speeds and combine "gentle" pumping with solids handling. Built for quick, simple maintenance, the low speed ensures long operating cycles. Positive displacement principles means easy, accurate flow control.

For waste water pumps the manner of installation deserves attention. Submersible pumps are easy to install and replace for maintenance. Dry pit pumps are usual in the case of high power capacities and generally operate at a higher efficiency. Their speed can be easily regulated and they can be more reliably supervised. They are, however, more costly to install. Due to maintenance problems and industrial safety requirements, the current trend is away from submersible to dry pit pumps.

15.5 Check lists for pump purchase specification

Many problems and unnecessary costs can be avoided if the following check lists are used. Irrespective of the method of purchase, "off the shelf" or by enquiry, the following data should be collated and reviewed by all interested parties. Although more than 100 check items are included under more than 15 main groups, they cannot be regarded as entirely exhaustive, because in certain special fields attention must be paid to some additional factors. Above all, check lists should be used when planning and purchasing pumping equipment for unusual, critical or difficult liquids.

For normal applications in a particular branch of industry, e.g. a dairy, or for a certain type of pump, e.g. submersible sewage pumps, a special check list or specification can easily be drawn up. Terms described as "rated" relate to the pump's normal operating conditions; the conditions to be reproduced during testing. Items designated with (pd) apply particularly to positive displacement pumps. It must be remembered in the context of constant speed positive displacement pumps that there can only be one rated flow. If maximum and minimum flows are specified the method of achieving the flow range must also be specified.

The data collated must be accurate. When accuracy is not possible, the data presented must be suitably qualified. There must be no ambiguity. The data collected applies to the pump, not the system. Some system data may be necessary, H-Q characteristic for variable flow systems in some cases, but this must be described as "system data". It is important that the data does not require interpretation. A pump manufacturer or distributor must not be required to "read-between-the-lines" to extract important information.

When users or contractors work on large installations some decisions taken early in the project are forgotten. All relevant data should be reviewed when preparing the final pump unit specification.

Liquid properties

See Table 7.18, Chapter 7.

Solids properties

See Table 7.18, Chapter 7.

Pump capacity

Suction head, pressure — minimum, rated, maximum

Suction temperature — minimum, rated, maximum

Rate of change of suction temperature

Flow — minimum, rated, maximum

Flow duration — constancy

Differential head — at minimum, rated, maximum flow

Suction and discharge pressure — at minimum, rated, maximum flow (pd)

Suction and discharge conditions at starting

Differential head for filling pipe system with consideration to possible syphon effects

Differential head affected by possible starting inertia of liquid

Discharge pressures for relief valve operation (pd)

Pump characteristic — rotodynamic or positive displacement

NPSHa, NPIPa — minimum, rated, maximum

Suction system — self priming, evacuation time

Flow regulation — throttling,
by-pass,

on-off,
load-unload,
adjustable guide vanes,
infinitely variable speed,
discrete speed steps,
manual or automatic control.
Needs system characteristic !
Possibility of liquid reverse flow ?
Also review Table 7.18, Chapter 7

Pump, mechanical requirements

Shaft deflection at seals at rated conditions
Service life of bearings at rated conditions
Suction pressure rating
Discharge pressure rating
Suction hydrotest pressure
Discharge hydrotest pressure
Suction connection allowable forces and moments
Discharge connection allowable forces and moments
Thermal growth of pump
Mean time between failures
Mean time to restore
Starting torque requirements
Permissible number of starts per hour
Permissible number of starts per year
Internal clearances
Changes in efficiency resulting from clearance variations
Dry running capabilities
Heat tracing or cooling
Warm-up time or cool down time
Hot stand-by
Extent of inspection without removing pipework
Extent of maintenance without removing from pipework
Access for cleaning out residue, if required
Effect of pump running backwards
Balancing
Vibration
Noise level
Possibility of modifying pump for duty changes; increased
impeller, plunger, piston diameter, de-staging

Shaft seal

See Table 8.1, Figures 8.30, 8.31 and 8.37, Chapter 8.

Material

See Table 7.18, Chapter 7.

Pipes and pipe connections

Type of connection — screwed, flanged, special
Special surface finish on flanges
Pressure ratings
Pipe movement and thermal strain
Flexible pipe connections
Pipe spools adjacent to pump
Suction pipe routing (NPSHa/NPIP_a)
Location of pump process connections
Minimum distance from pump to bends or valves
Location of pump auxiliary service connections

Isolating valves
Non-return valves
Relief valve (pd)
Tapping points for measuring pressure and/or temperature
Possibility of water hammer during normal start
Possibility of water hammer during normal stop
Possibility of water hammer if power failure
Allowable axial shaking forces for pressure pulsations (pd)
Insulation against heat and/or cold
Heat tracing
Design and facilities for mechanical cleaning or
inspection by “pig”
Will pump manufacturer review and advise on pipework (pd)?
Acoustic and mechanical analysis of pipework (pd)

Drivers

Electric motor:

type,
speed(s),
AC / DC,
speed regulation,
direction of rotation,
voltage, phases, frequency,
method of starting,
starting torque characteristics,
number of starts per hour,
area classification,
certification,
type of physical protection,
cooling system,
power, minimum, rated, maximum,
efficiency and power factor,
bearings and lubrication,
space heaters,
location of terminal box,
electrical protection/monitoring
equipment,
thermal growth,
balancing,
vibration,
noise level.

See Chapter 10.

Engine:

speed,
speed/torque characteristic,
naturally aspirated, turbo-charged,
direction of rotation,
governor,
fuel, dual fuel, calorific value,
fuel consumption,
efficiency,
method of starting,
cooling system,
time to warm-up,
controls and instruments,
auxiliary equipment,
waste heat boiler,

hazardous area modifications or
mount in safe area,
thermal growth,
balancing,
vibration,
noise level.

See Chapter 6, Sections 6.9.2 and the end of Chapter 10.

Turbine:

speed,
speed/torque characteristic,
direction of rotation,
condensing/pass-out,
steam conditions,
governor,
over-speed trip,
steam consumption,
efficiency,
bearings and lubrication,
barring system,
time to warm-up,
steam valves,
controls and instrumentation,
thermal growth,
balancing,
vibration,
noise level.

See Chapter 6, Section 6.9.2 and the end of Chapter 10.

Drive train

Couplings:

service factor,
maximum speed,
spacer length,
long spacer for fire wall,
capacity for misalignment,
mounting,
balancing,
lubrication.

See Chapter 9.

Gearbox:

service factor,
service life of gears and bearings at rated conditions,
exact ratio,
efficiency,
cooling,
bearings and lubrication,
minimum speed,
thermal growth,
balancing,
vibration,
noise level.

See Section 11.4, Chapter 11.

Vee-belts:

service factor,
ratio,

efficiency,
cooling,
pulley balancing,
noise level.

See Section 11.3, Chapter 11.

Ancillary equipment

Baseplate, skid, trailer, lifting frame — see Chapter 11, Section 11.2.1

Relief valves — see Section 11.5 (pd)

Accumulators — see Section 11.7

Pulsation dampers — see Section 11.8 (pd)

Instrumentation — see Section 11.9

Environment

Stand-by facilities

Electricity supplies

Auxiliary services supplies

Industrial safety standards

Overall pump package noise level

Allowable transmitted vibration level

Leakage in the form of liquid

Leakage in the form of vapour

Safety with respect to hazardous gasses

Radiation of heat

External condensation on cold surfaces, possible formation of ice on pump

Permissible gas concentration in premises (ppm) and necessary ventilation

Atmospheric pollution

Biological attack

Altitude

Weather variations

Indoor, outdoor, onshore, offshore, sheltered, sunshade, attended, unattended

Erection and installation

Horizontal or vertical shaft

Submerged pump

Space and transport routes for erection and maintenance

Lifting facilities for installation

Lifting facilities for maintenance

Foundation; concrete, structural steelwork

Dynamic loads on foundation

Static loads imposed by pipework

Space for future developments

Drainage for safe leakage

Drainage for hazardous leakage

Drainage of the pump contents

Drainage of lubricants and cooling liquid

Vents for hazardous vapour

Vents for steam

Maintenance

Parts lists and cross-sectional drawings

Lubrication schedule

Routine maintenance instructions

Repair instructions

Trouble-shooting guide for all equipment
 List of rapidly wearing parts with predicted life
 Quotation for commissioning spares
 Quotation for 1 years operations spares
 Quotation for 2 years operations spares
 Quotation for insurance spares
 Quotation for special tools
 Pump curves
 Locations of measuring points for preventive maintenance
 (vibration, temperature, electric current, etc.)
 Hours-run meter
 Staff training
 Location of manufacturer's nearest service centre
 Location of manufacturer's nearest spares stockist

NOTE: Manufacturers will not supply drawings of spare parts. Drawings contain proprietary information which is confidential. Using spare parts manufactured by others will invalidate any guarantee or warranty. The pump manufacturer has no responsibility for the damage caused or production lost due to "pirate" parts.

Quality Assurance

Pumps designed and built to a standard
 Pumps manufactured to a standard
 Fully assembled pump subjected to a running test
 Fully assembled pump subjected to a pressure test
 Typical batch size of mass-produced pumps
 Number of pumps in a batch tested
 Tolerance band on published pump performance data
 Fully assembled pump unit tested
 Which standard is used for testing?
 What quality assurance documentation supplied?

Purchase conditions

Quotation validity
 Length of guarantee for workmanship and materials
 Delivery time
 Point of delivery
 Price
 Currency
 Drawings
 Manuals
 Certification
 Erection at site
 Commissioning

NOTE: Manufacturers are unlikely to give a guarantee regarding the performance of the pump at site or how the performance will degrade with time. The pump performance and life are greatly affected by the quality of the installation and particularly by the pipework design. Pump manufacturers are not normally involved in the foundation design or the pipework design. Bearing life can be shortened dramatically by poor foundations, misalignment and pipe strains. Pump performance can be severely impaired by poor pipework design. The pump manufacturer shows how the pump can operate by testing in the factory. The factory tests should be conducted as close to the site operating conditions as possible. A site simulation test may be possible. Except in the cases of fully packaged equipment such as portable high pressure cleaners, factory testing cannot reproduce site conditions. Problems such as acoustic resonance or pipework vibration can only be detected by computer simulation. The pump manufacturer should be prepared to work at site to analyse and isolate problems. The pump user must be prepared to pay the pump manufacturer for solving problems outside his sphere of control.

15.6 Purchasing

Chapter 4 deals with the criteria and standards which are of prime importance in connection with specification. Chapter 12 deals with the implementation of testing and quality controls. These are concerned, amongst other things, with guarantees of performance and quality. Criteria for service life and reliability are lacking however. Over and above the technical requirements, suitable general terms of delivery should be drawn up.

In the processing industry and at refineries API 610, 674, 675 and 676 are usually applied as requirement criteria as they specify in detail how a pump should be designed, manufactured and tested. Reference may be made where applicable to API standards for guidance for pumps to meet these requirements. However, it must be remembered that an inspector looking at a pump cannot certify that it will be capable of operating without interruption for three years.

The purchase documents should contain references to legislative regulations and requirements affecting design, to the properties of the liquid as well as to operating conditions and function of the pump in order that the manufacturer may be able to determine the necessary material and the design of the pump. There is no point in referencing obscure regulations. Manufacturers do not have easy access to all standards and legislation. If particular, local regulations must be observed, a copy should be supplied with the enquiry.

It is important that the specifications detail the pump operations. Safety margins should be shown separately as such.

Remember the site cost-saving edict:

"Trouble-shooting is making the pump do what you specify. Making the pump do what you want is up-grading!"

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Pump applications & solutions

16

16.1 Modern pumps for hydrocarbon-based and synthetic heat-transfer oils

- Introduction
- Pump performance
- Pump design
- Seals and bearings
- The pump units
- Temperature considerations
- The carbon bearing
- Bearing geometry

16.2 Pumping fresh water to a high reservoir

- Operating conditions
- System curves
- Choice of pumps
- Installation of pumps

16.3 A small sewage pumping station

- Introduction
- Pump and system curves
- Operating conditions

16.4 A fresh water booster station

- Method of operation
- Pump curves
- Valves
- Control
- Operating sequence
- Limitations of operation

16.5 Magnetic drive pumps for Chlor-alkali manufacturing — mercury cell processing

- Introduction
- The mercury cell process
- The pump
- Mercury emissions

16.6 Domestic heating systems and pumps

- Introduction
- Boiler
- Expansion vessel
- Pipes
- Radiators
- Hot water for taps
- Mixing valve
- Clock-thermostat
- Automatic control centre
- Thermostat valves

- Design temperature

- Pump

- Pitfalls

16.7 Adjustable jet pump

- Introduction
- Description
- Regulation
- System properties

16.8 Updating of water supply for industrial use

- Control before updating
- Control after updating
- Alternative control
- System details
- Operational results after updating

16.9 Economic aspects of energy utilisation

- Choice of pumps
- Definitions and assumptions
- Standard motor pump units
- Wet rotor motor pump units
- Equations
- Comparison
- Conclusions

16.10 Pumping of delicate solids – food and live fish

- Introduction
- Pumping food
- Pumping live fish

16.11 Submersible sump pumps for construction projects

- Introduction
- Types of drainage
- General plant information
- Pump sizing data
- General installation instructions for drainage
- Flexible pipes

16.12 Use of engine driven self-priming pumps

- Pumping unit
- Size of pumps
- Site installation
- Pumping
- Pitfalls

16.13 Cargo pumps for tankers

- Large tankers for crude oil

Smaller tankers for finished products

LNG carriers

16.14 Detergent manufacturing systems — pump installations

Introduction

Pumping the raw material

The mixer

Finished detergent pump

16.15 High capacity bearings for compact centrifugal pump systems

Introduction

The need for compact bearings

Improved life and increased dynamic load ratings

16.16 Energy recovery turbines and reverse running centrifugal pumps

Introduction

Energy recovery and its uses

Reverse running pumps

Fundamentals

Effects of power recovery

16.17 Common errors which create pump operating problems

Planning of pipework

Liquid properties

Equipment positioning

Pipework design

16.18 Positive displacement pumps — load-unload control systems

Introduction

Typical system

Electric motors

Operation

Bypass valves

Damping

16.19 Plunger pumps for supercritical extraction service

Introduction

Background

Applications

The process

A high pressure supercritical recycle process

Supercritical extraction system

Liquid carbon dioxide pump requirements

Summary

16.20 Sealing systems for thermal oil pumps

Introduction

Pump concepts

Sealing systems

Field experience and application

Pump selection

16.21 Progressive cavity pump stator technology for improved candy production

Introduction

The progressive cavity pump

Even Wall® stators

Summary

16.22 Digital controllers for diaphragm dosing pumps with speed-controlled drive motors

Introduction

Reasons for dosing errors

Conventional solutions for monitoring volumetric flow

Operating principles of the flow monitor

Error detection

System solution

Summary

16.23 Positive displacement medium pressure pump system for tube press application

Introduction

Technical application

The solution

After installation

16.24 Boiler feed pump for efficient power station operation

Introduction

Turbine drives pump

Special vane profile

Hydraulic design

The first stage impeller

Simulating flow in the impeller

Cavitation testing

The rotor

The shaft bearings

The stationary components

Taking on 36.75 MN!

Shaft seals

Planned maintenance

A “well-tempered” pump

Remote monitoring accompanies commissioning

Summary

16.1 Modern pumps for hydrocarbon-based and synthetic heat-transfer oils

Introduction

As soon as the temperature in a heat-transfer system becomes too high for water, a plant operator must choose between hydrocarbon-based or synthetic oils as the heat-transfer liquid. This usually happens once process temperatures in excess of 200 °C become necessary. Until recently, hydrocarbon-based heat-transfer oils were often the first choice simply because they cost less. But synthetic oils are now beginning to assume a more prominent role.

The advantages of synthetic oils are appreciated over the long term. Synthetic oils pay for themselves in just a few years, with the exact time depending on the application, the system, and of course the temperature. This is especially important since as temperature rises, a greater amount of decomposition products with varying boiling point properties will form in the oil. These contaminants influence the properties of the heat-transfer liquid itself – usually in a negative way. The consequences extend beyond just having to replace the thermal transfer fill more often. More serious are deposits that form in the system, since these are difficult or impossible to remove. An operator's choice of oil will determine whether new oil is needed every year, every three years, or longer. In fact, when modern synthetic oils are used, systems with process temperatures up to about 300 °C can stay in service for their entire service life with one fill. So clearly, synthetic oils are worth the significantly higher price.

Furthermore, once process temperatures rise above 300 °C, only high quality synthetic oils will be appropriate. At these temperatures, service life will be dependant on the chemistry of the thermal transfer liquid; one has to look at more than just the maximum permissible process temperature to make a judgment. Also important, is the fact that even with these products, any increase in temperature will affect service life. Ten degrees Centigrade one way or the other will influence how long the oils can stay in service: ten degrees higher usually doubles the product's rate of decomposition. In any case, more costly maintenance of the system will be required. However, when compared to hydrocarbon-based heat-transfer oils, the amount of maintenance associated with synthetic oils is significantly lower.

Pump performance

The quality of the oil also directly influences pump performance. If a large number of low-boiling point compounds form pockets of vapour in the pump, it will lose prime and stall. Under these conditions, the pumps no longer run at design conditions. They are subjected to higher stress and have lower pumping performance. This becomes a vicious circle where low-boiling point compounds reduce pump flow, which increases stress on heat exchanger heating surfaces (higher metal temperatures), accelerating decomposition of the thermal transfer oil (higher localised oil temperatures), and ultimately forming more vapour bubbles and surface fouling. Nevertheless, synthetic heat transfer oils do place special demands on pumps. Compared to hydrocarbon-based oils, their lubrication qualities are much poorer.

Pump design

Hot-oil pumps have been specially designed that are specifically adapted to the properties of synthetic oils. Two factors are critical: poorer lubrication and often lower viscosity, which are essential because these properties improve the transfer of heat. These two factors make traditional pump designs inadequate. Starting the pumps is difficult, since low viscosity liquids do not generate an adequate lubricating film at low surface

speeds, and high wear is to be expected – and therefore higher maintenance costs – when they are in service.

Seals and bearings

In particular, the presence of low-boiling point compounds in the synthetic oil places great stress on the mechanical seals. Special design solutions are needed to compensate for this stress. A large sealing area and the ability to collect vapours in a special section of the pump (where they can be easily removed) are critical for extending the pump's service life and increasing its reliability. When used for hot water applications, dissolved gases which evolve during heating can be collected here. In addition, the bearing and the seal must be adapted precisely to each other, the low viscosity, and the overall application.

Carbon bearings combined with non-relieved mechanical seals and silicon carbide bearings combined with relieved seals have proved invaluable. These combinations also make the pumps insensitive to sludge and other types of solid contamination in the oil. Finally, quench liquid buffers further increase the service life of the mechanical seal and provide greater security against leaks. A quench further reduces temperature at the mechanical seals and eliminates the possibility that fluid leaking out of the seal will oxidise and cause damage to the seal. See Figure 16.1.

This principle also makes it possible to use non-hermetic pumps with nasty liquids (hazardous, flammable, toxic and noxious) since the use of a non-critical quench liquid greatly thins the pumped liquid in a way that is comparable to the effects of a corresponding double-action mechanical seal. From the operation and efficiency point of view, non-hermetic pumps have the advantage that they consume less power since there will be lower frictional losses from the pump rotating parts and no eddy current losses during the transmission of power.

The pump units

The low cost pump units handle both low viscosity, synthetic heat-transfer oils up to 350 °C as well as hot water up to 207 °C with the identical material configuration. They make traditional water pumps with special seals obsolete.

The pump units employ a flexible modular system. Depending on the specific application, they are available in mono-block, bearing bracket and in-line versions. They are economical to produce and simple to maintain and a uniform combination of

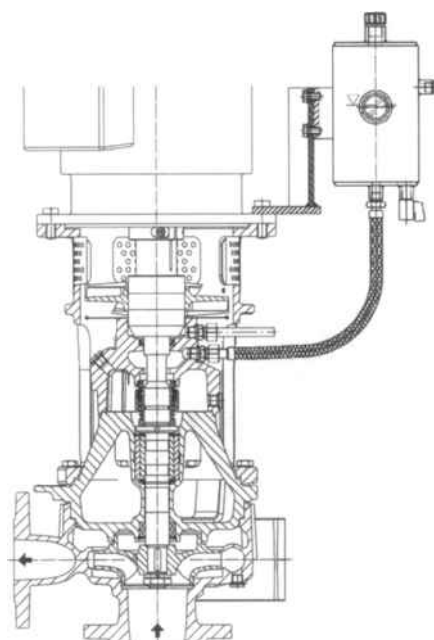


Figure 16.1 A vertical mono-block pump with quench tank
Courtesy of Allweiler AG

materials - cast iron, nodular cast iron and 13% chrome - covers all pumped liquids.

There are 12 possible combinations – ready for the most diverse applications – using a few basic components: the three design types, two casing designs, PN 16 with dimensions according to EN 733; and PN 25 with dimensions according to EN ISO 22858) and two bearing/seal combinations:

Silicon carbide bearing combined with a balanced mechanical seal for hot water up to 207 °C

Carbon bearing combined with a non-balanced mechanical seal for hot water up to 183 °C and most applications involving heat-transfer oils.

Temperature considerations

When synthetic oils are used, the application usually involves a high-temperature system where large temperature differences are a major factor. These make expansion movements within the pump unavoidable due to external forces that affect the pumps through the system and the piping. That is why pumps for synthetic oils in particular must be mechanically very durable and rigid, but without transferring too much heat to the bearing and shaft seal.

The range of pumps can handle this situation, since the process liquid lubricated bearing is no longer part of the bearing housing, but instead is now part of the casing cover. It is therefore possible to move the separating interface between the casing cover and the bearing housing even further toward the drive end. At the same time, the diameter of the sealing face/spigot and therefore the centre between the two parts has been enlarged. The result is an optimised, skeleton-frame-type structure whose mechanical stiffness equals that of bearing housings found on traditional centrifugal pumps. Making the inboard bearing part of the casing cover also increases the length of the thermal barrier protecting the mechanical seal and outboard bearing. In this way, a low temperature level is achieved without the need for cooling ribs. The position of the interface also en-

ables additional savings, since it is possible to forgo a second 'seal housing' for the mechanical seal. See Figures 16.2 and 16.3.

Since the plain bearing is located behind the heat barrier where temperature is lower, there is no possibility of dry-running in the bearing. In designs where the bearing is located directly behind the impeller, by contrast, dry-running can occur as soon as the pumped liquid gets close to its vapour point – even when the pump is filled! Thanks to its lower temperature, liquid in the plain bearing of the pump is always sufficiently pressurised. Furthermore, optimisation calculations have shown that, assuming the same bearing geometry behind the heat barrier, this design provides an ideal lubricating film thickness in the bearing, maximising its effectiveness. The higher viscosity of the liquid more than compensates for the less ideal impeller cantilever length.

The carbon bearing

Practical tests have shown that the specific configuration and design of the carbon bearing generally result in a stable lubrication film. As long as the pumped liquid is free of particularly abrasive, fine-grain constituents, the carbon bearings will be subject to virtually no wear. Even normal contamination like corroded flakes from the pipes of hot water systems are not a problem, since a safety throttle keeps most of it away from the bearing. The throttle is located in front of the heat barrier and directly behind the impeller where it protects particularly against elevated leakage if the main seal fails. As a result, the bearing will achieve the stated long service times even when the pump is operated close to the minimum volume limit. The two bearing types – carbon and silicon carbide – are mutually exchangeable by changing the inner unit, which consists of the shaft, bearing and shaft seal.

The mechanical seal has been moved away from the impeller in the sealing area. The large-volume seal housing is designed to strip gas bubbles from the mechanical seal, collect the gas/vapour, and vent the pump. This protection against dry-running greatly lengthens the service life of the seal when pumping liquids with low lubricity that also tend to emit gas, even when the pump is in a vertical position. The bearing housing can also be used for the mono-block and in-line pumps, which are often installed vertically without loss of functionality. See Figures 16.4 and 16.5.

Bearing geometry

For heat transfer pumps the bearings are not pressed in, but instead allowed to tilt. This has two benefits:

First, if a bearing bracket is not aligned and centred precisely after maintenance, for example, it will automatically find its proper position,

Second, the bearing will move naturally if there is pressure from the shaft. This avoids point strains and lengthens service life.

A spacer coupling utilising two Cardan joints is used for all high-temperature applications and especially for systems that

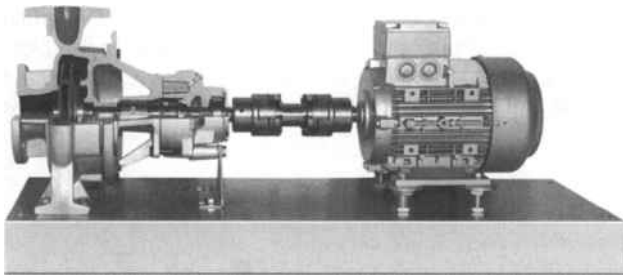


Figure 16.2 The bearing bracket pump
Courtesy of Allweiler AG

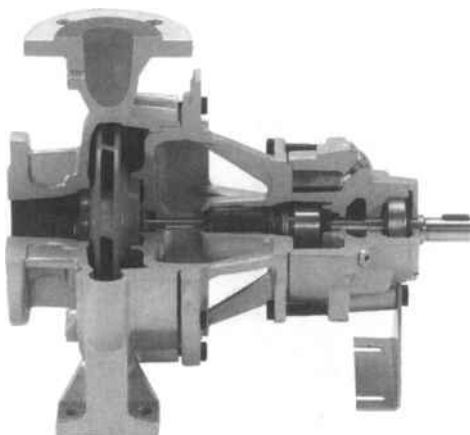


Figure 16.3 Section through the pump
Courtesy of Allweiler AG

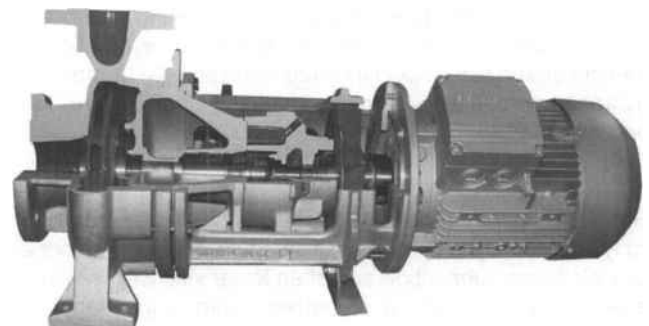


Figure 16.4 Section through the mono-block pump
Courtesy of Allweiler AG



Figure 16.5 Section through the in-line pump
Courtesy of Allweiler AG

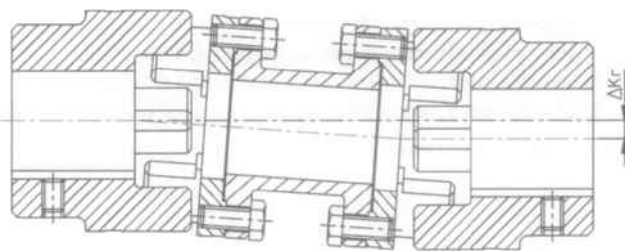


Figure 16.6 Spacer coupling
Courtesy of Allweiler AG

exhibit large thermal growths. These couplings safely accommodate even very large misalignments. See Figure 16.6.

Special heat-transfer pumps also provide a high level of investment security. If system is to be converted to modern synthetic oils, existing pumps can be adapted to the elevated temperature requirements by replacing the insert units. Such versatility from using a single pump type in a variety of heat-transfer liquids greatly simplifies processes for the operator and plant designer.

Application courtesy of Allweiler AG

16.2 Pumping fresh water to a high reservoir

Operating conditions

The clean water collected in a low reservoir, is to be pumped up to a high reservoir. The high and low water levels in the two reservoirs and the altitude of the site for the location of the pump are shown in Figure 16.7. The pipe linking the reservoirs is long, about 20 km, and during much of the day water is drawn from the pipe by consumers with consequent loss of pressure.

The daily consumption of water varies considerably. Furthermore, other water resources are operated simultaneously. For these reasons and also with regard to economy it must be possible to adjust the pumping from the water works in question from between about 50 to 115 litres per second. In cases of emergency, it should be able to pump about 170 litres per second.

System curves

The system curves are shown in Figure 16.8. It proved possible to install the pumps 1 metre below the lowest water level in the low reservoir so that a positive head of 1 to 3 metres was obtained on the suction side. At the high reservoir the difference in height between high water and low water is 5 metres. The

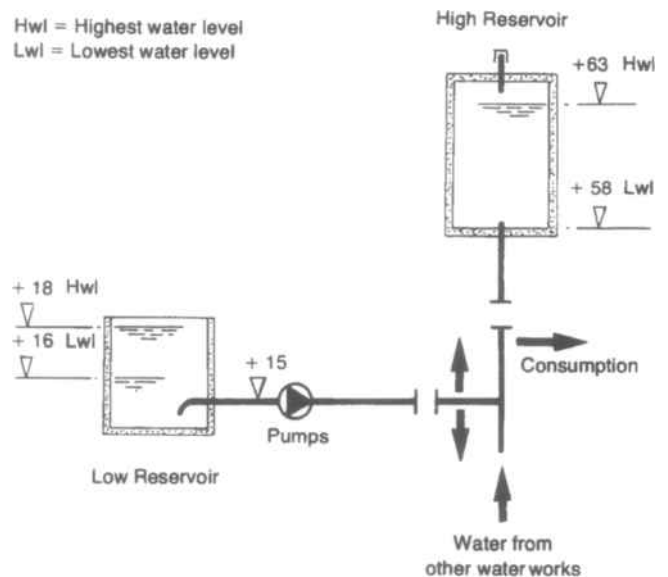


Figure 16.7 The system

static delivery head in the system therefore varies between 47 m (+63 - +16) and 40 m (+58 - +18).

The losses in the pipe system are shown by curves A and B in Figure 16.8. From time to time the high reservoir may be disconnected for cleaning purposes or as the result of a breakdown. Pumping must then be directed to another higher reservoir and this results in an increase of static losses by about 3 m. Curve C illustrates the upper limit of the head requirement in this situation. The normal operating zone for the pumps is clearly indicated in Figure 16.8. The highest operating efficiency should therefore lie within this zone.

Choice of pumps

On the basis of the great variations in flow demand, and respective head requirements found in this case, a combination of pumps was deemed necessary. However, it was scarcely possible to find space for more than three. High reliability of operation required that a stand-by unit should, at least to some extent be available. The necessary delivery heads implied that virtually only centrifugal pumps could be considered. From the running and maintenance points of view it was desirable that all the pumping units should be identical.

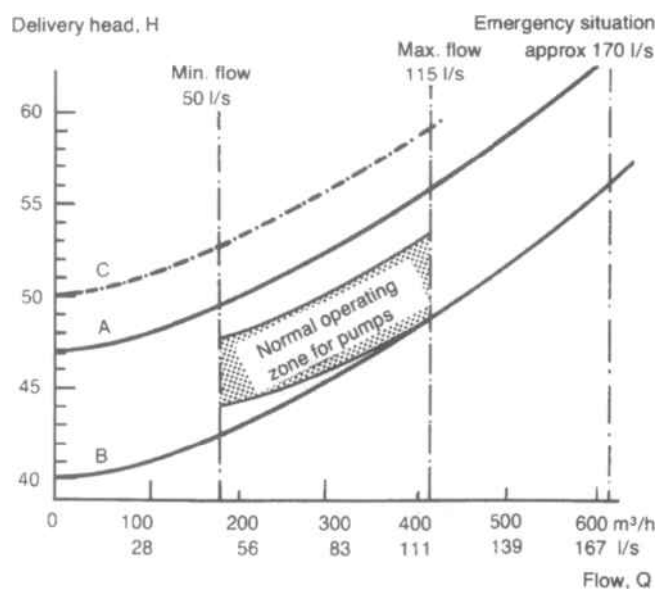


Figure 16.8 System curves

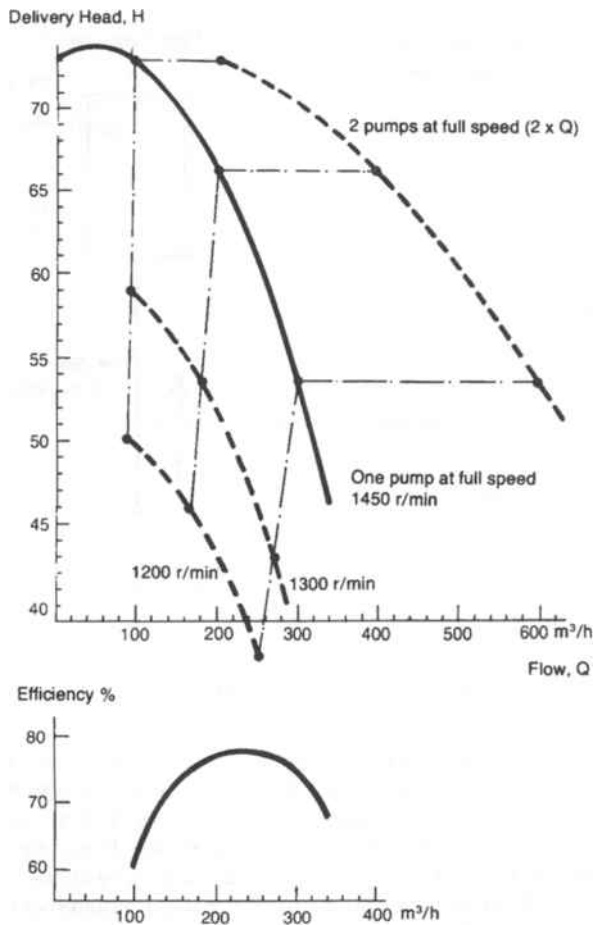


Figure 16.9 Pump curves

For the best possible reliability, company policy was to use pumps running at 4 pole motor speeds. Standard, double suction axially-split pumps would only fit the duty when running at 2 pole speeds. The use of three pumps would mean a motor power of 55 to 75 kW depending upon the pump efficiency. It had been decided to use a variable speed DC motor on one pump for supply adaptation. Mass-produced DC motors of the size necessary only ran up to 2200 rpm. Eventually a two stage axially-split pump was found; the first stage being double suction for good suction performance.

The pump curve is shown in Figure 16.9. Curves calculated according to the Affinity Laws for 1200 and 1300 r/min are also shown in the Figure, as well as a combined curve for two pumps at full speed of 1450 r/min. The efficiency curve is also included in the Figure.

In Figure 16.10 the pump curves have been overlaid on the system curves. As may be seen, the speed regulated pump provides the desired minimum flow at a speed between 1200 and 1300 r/min. Maximum flow was obtained with a constant speed plus the speed regulated pump. One unit was then kept in reserve. An emergency temporary demand of 170 litres per second can be met with all three pumps in operation.

The efficiency of the constant speed pumps is not the best in their normal operating zone, only about 70%, but it is better than that obtainable with faster pumps having cut-down impellers.

The maximum power requirement for the pumps selected occurs at $H = 46$ m and $Q = 340$ m³/h, see Figure 16.9, and is 61 kW. The efficiency of the electric motor is estimated to be 90% and the pumping units are supplied with 75 kW standard 4 pole squirrel cage motors.

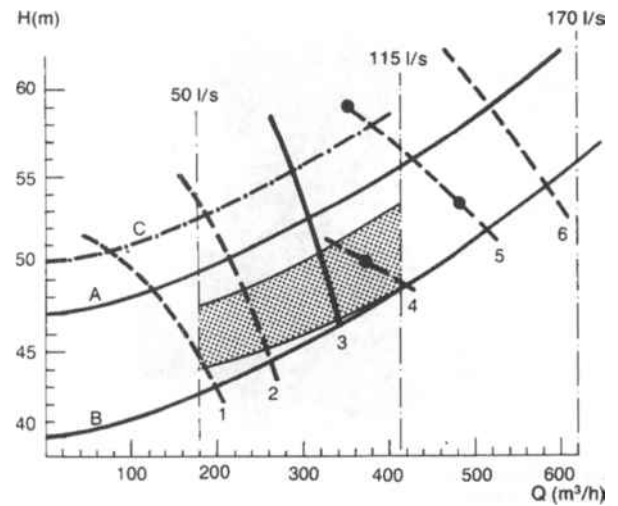


Figure 16.10 Pump and system curves

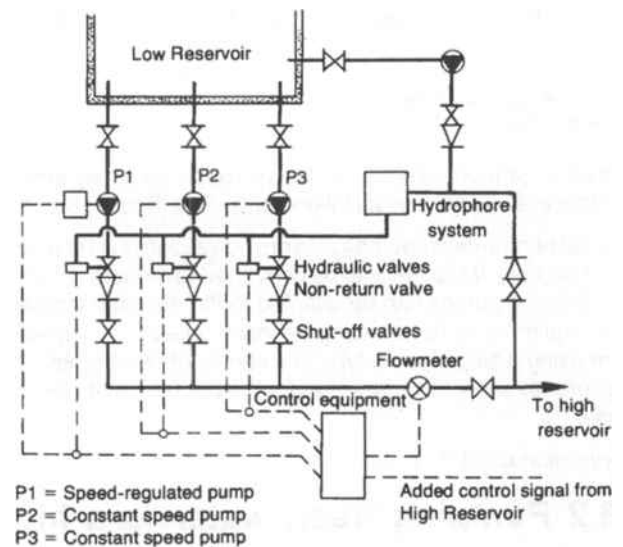


Figure 16.11 Schematic arrangement of pump installation

Installation of pumps

Figure 16.11 indicates schematically how the pumps were installed. The pumps work in parallel with the speed regulated pump as the lead unit. When this reaches full speed, one of the two constant speed pumps is started; the constant speed pumps operate alternately, controlled by switched sequencing, and the speed regulated pump reduces to its minimum speed. In the case of increasing flow requirements it increases speed again. The procedure is the reverse in the case of decreasing water requirements.

Control of the variable speed as well as the starting and stopping of the constant speed pumps is regulated by a theoretical daily demand which in turn is constantly corrected by input from the water level in the high reservoir.

The delivery pipes of the pumps are fitted with hydraulically controlled, slow operating valves to reduce water hammer when starting and stopping. Pumps are therefore always started with the valve closed and when stopping the valve closes first. For safety reasons the pumps are also supplied with non-return valves.

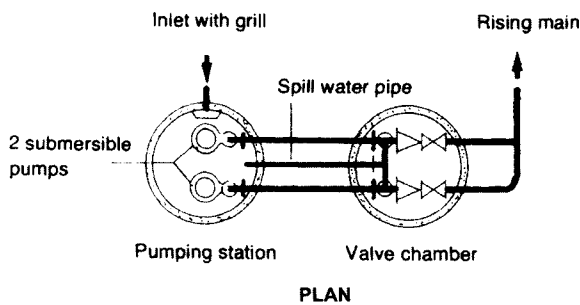
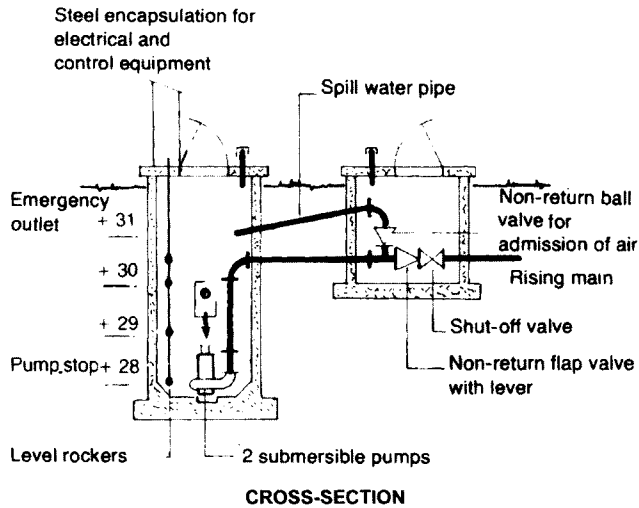


Figure 16.12 Arrangement of a small sewage pumping station

16.3 A small sewage pumping station

Introduction

The pumping station serves a small housing estate. The supply of sewage during the initial period is a minimum of approximately 1 litre/s and a maximum of approximately 5 litre/s. It is estimated that gradually the minimum flow will increase to 2 litre/s and the maximum will increase to about 8 litre/s. The positive elevations at the pumping station are shown in Figure 16.12. The rising main from the station is about 700 m long and discharges into a well at level +55 m. The diameter of the pipe is 150 mm and the volume is thus about 12.4 m³.

As may be seen in the Figure, pump stop occurs at +28 m. The station has an emergency outlet, or overflow, at +31 m. The static delivery head will be maximum $55 - 28 = 27$ m and minimum $55 - 31 = 24$ m. The stop level of the pumps has been placed as low as possible, approximately 250 mm above the floor in the pump sump, in order to avoid the formation of sludge deposits.

The station consists of two units, the pumping station itself and a valve chamber. The pumping station is constructed of pre-cast concrete rings with rubber joints. The internal diameter is 2 m and the volume per metre of height is about 3.14 m³. The station is equipped with two identical submersible centrifugal pumps with quick release pipe couplings to allow quick pump removal. The pumps are started and stopped via level rockers, one of which is also used to transmit a signal to the control centre when the water level in the station is too high. Level rockers are proprietary level switches which change attitude when floating on the liquid surface or are submerged.

In the valve chamber, which is also constructed of pre-cast concrete rings, there is a system of valves which ensures reverse-flushing of the pumps at every stop to prevent clogging.

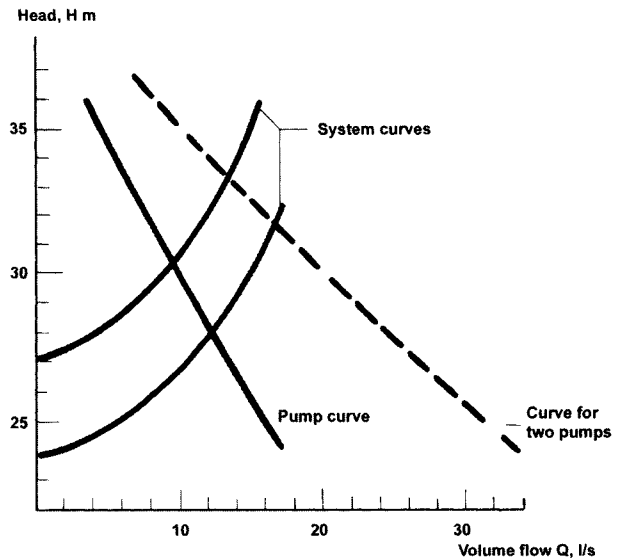


Figure 16.13 Pump and system curves

During pump shut-down, air is introduced into the system via the non-return ball valve, the ball should have a specific gravity of 0.9 to function efficiently and the water in the rising main in front of the flap non-return valve flows back to the pumping station and flushes the pump clean. The amount which flows back in this particular case is about 90 litres. Thus for a short time the pump rotates backwards.

When the pump starts up it is impossible to prevent a slight jet of liquid being expelled through the non-return ball valve as this cannot be closed instantaneously. A spill water pipe returns the liquid to the pumping station.

Pump and system curves

These are illustrated in Figure 16.13. As stated, the static rising delivery head can vary between 27 m and 24 m. The losses in the rising main and its valves are shown by the system curves. The size of pump chosen has flows from 9 to 12 litre/s, depending on the differential head. Figure 16.13 also shows the curve for both pumps in operation. The efficiency of the pumps in the operating zone is about 70%. The size of the motor is 9.6 kW, the normal output being about 6 kW, corresponding to a current of about 12 A. The pumps are started direct-on-line.

Operating conditions

As mentioned, the flow of sewage to the station in the initial period is 1 to 5 litre/s. The volume of the pump sump is about 3140 litre/metre height. Pumping should occur at least once every

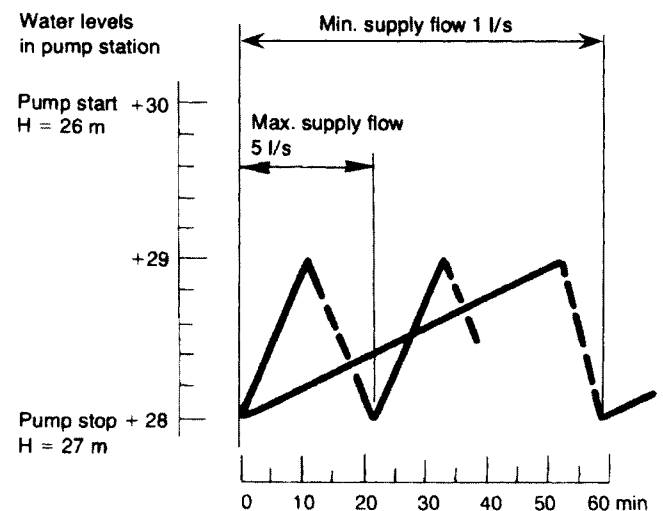


Figure 16.14 Operating sequence with 1 m working level

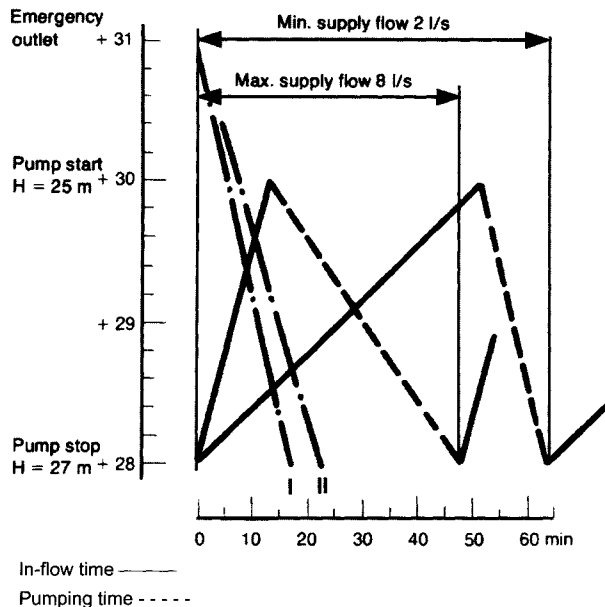


Figure 16.15 Operating sequence with 2 m working level

hour to ensure water replacement. The start level of the first pump has therefore been provisionally adjusted to level +29 m, see Figure 16.12, i.e. when 1 m of the sump is utilised. The operating sequences will then be as shown in Figure 16.14. At minimum supply flow the sump used is filled in about 52 minutes, $3140/(1 \cdot 60)$ and pumping takes place for about 6 minutes. Output is approximately 10 litre/s at $H_{\text{mean}} = 26.5$ m, see Figure 16.14, minus inflow, i.e. $3140/((10^{-1}) \cdot 60)$.

As already mentioned, the volume of the rising main is 12.4 m^3 and after 4 hours the water in the pipe has been replaced. At maximum inflow the sump level rises sufficiently in 10.5 minutes and pumping out takes equally long, pump start occurring every 21 minutes. The pump motor is rated at 15 starts per hour.

Gradually, as the minimum and maximum rates of flow are increased, the sump volume will also be increased. Figure 16.15 illustrates operating conditions at full supply flow and when 2 m from the sump, a volume = 2×3140 , is used. This Figure also includes two curves, I and II, showing the time required for the emptying of the station from the emergency outlet level, e.g. after a power failure, with one pump in operation and minimum in-flow, I, and both pumps in operation and maximum inflow, II.

In calculating these times no allowance has been made for the reverse-flushing flow volumes. These, however, would be a marginal effect only.

As may be seen from this, normally only one pump is required to operate. Changeover takes place at every pump start so that both units are used. The second pump therefore acts as a standby and is started when the level in the sump exceeds the permissible value, +30.5 m. This situation can occur when:

- The lead pump fails
- The lead pump is partially blocked
- There is high rain water inflow

The station is monitored by an alarm system via telemetry and is inspected only once a week, when the sump is flushed clean and functional checks, etc., are carried out.

16.4 A fresh water booster station

The function of the booster station is to create the necessary increase in pressure for the distribution of water in the higher areas of an urban district. Figure 16.16 illustrates the schematic arrangement of the booster station and its control system, which has been in operation for 20 years or so.

Method of operation

Normally, the pump operation will be automatically adjusted to water consumption in the high area in such a way that the pressure in the distribution pipe is maintained more or less constant. Adjustment to the actual pressure is affected partly by means of changes in speed of one of the electrically driven pumps and partly by changing the number of pumps in operation. Variable speed is obtained by the use of a DC motor.

Pump curves

The effects of running the pumps in combination are shown in Figure 16.17.

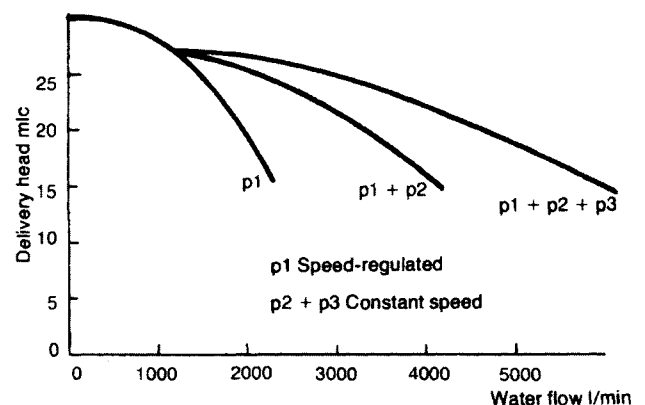


Figure 16.17 Combined pump curves

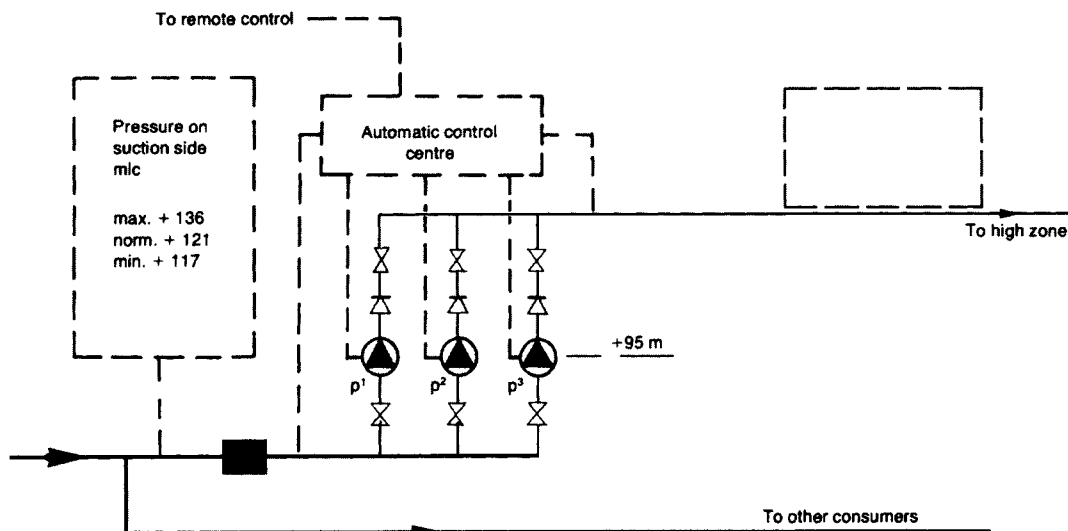


Figure 16.16 Schematic arrangement of booster station and control system

Valves

Each pump has a manual isolation valve located in the suction pipe to the common suction header. Each pump is fitted with a non-return valve and an isolating valve in the discharge connection to the common header. The gate valves are of the full bore rising stem design. A mechanical indicating, totalising flow meter is fitted in the booster station supply pipe.

Control

A pressure transducer, fitted to the distribution pipe, measures the changes in pressure caused by variations of consumption and transmits signals to the logic controller. This initiates the necessary changes in speed and number of pumps operating so that the pressure is restored to the predetermined value.

The pumping station operates without local personnel supervision. Control is performed by monitoring the water pressure on the delivery side of the pumping station with a local logic controller. In addition, certain fault condition signals are transmitted to the central control station.

Operating sequence

When water consumption is low, the speed regulated pump, p^1 , operates alone. Speed is increased as consumption increases. When consumption surpasses the capacity of p^1 , either p^2 or p^3 is brought into operation. Which of the two pumps, p^2 or p^3 , is to be started up is decided manually by a lag-lead switch or automatically by a timer. With the intention of reducing variations in pressure experienced when starting a constant speed pump, the speed of pump p^1 is reduced as another pump comes into operation. A similar procedure is followed when a constant speed pump is withdrawn from operation. At peak consumption all three pumps are in operation.

Limitations of operation

Pumping station operation is suspended in the case of insufficient pressure on the suction side or excessive pressure on the delivery side. Not until the pumping station has been inspected is it possible to start up the pumps again. The speed regulated pump can only be started at minimum speed.

16.5 Magnetic drive pumps for Chlor-alkali manufacturing — mercury cell processing

Introduction

Chlor-alkali electrolysis is one of the most important processes in the chemical industry and provides the basic chemicals chlorine (Cl_2), caustic soda (NaOH) and hydrogen (H_2). Chlorine

and sodium hydroxide are among the top ten chemicals produced in the world.

Important products that contain chlorine or where chlorine is involved in the manufacture are medicines, pigments, pesticides and plastics such as polyurethane, polycarbonate, epoxy resins, silicone and PVC. Chlorine likewise plays an important role in the manufacture of high purity silicon for use in electronics, and in the production of TiO_2 for the extraction of white pigments.

Caustic soda is used in large quantities for the treatment of effluent and in the breakdown of bauxite in the manufacture of aluminium. Caustic soda is also needed for the extraction of cellulose, in the production of phenol resin and in the processing of cotton. Another important use of caustic soda is in the manufacture of detergents and soaps.

The hydrogen gained during the electrolysis is of secondary importance.

The mercury cell process

Both chemicals are produced through electrolysis of sodium chloride (salt, NaCl). The mercury cell is one of several industrial processes which use electrolysis to split sodium chloride. Mercury is of course a very poisonous substance.

Salt brine is introduced into a container (cell) with two electrodes from a DC power source. The carbon anode (negative electrode) is suspended from the top. Mercury flows along the floor of this chamber in the opposite direction. The mercury goes into a chamber underneath, where water flows in the opposite direction. Chlorine is collected from the carbon anode, and sodium is recovered from the cathode. A pump returns the mercury to the top chamber.

A typical cell is approximately 2m wide and 10m long. A plant consists of many cells operating in parallel (see Figure 16.18).

The mercury cell cathode consists of a slowly flowing layer of mercury across the cell bottom. Sodium/mercury amalgam is produced at the cathode and flows to a separate reactor, known as the decomposer. The amalgam is reacted with water to produce hydrogen gas and caustic soda solution. A 50 % caustic solution is produced directly from the cell.

The pump

When mercury functions as an electrode, it is not consumed in this closed-loop process. Mercury is circulated from the decomposer back to the cell using a centrifugal pump. Several different pump types are used. The pump seal is an obvious leak point for mercury. Early sealless pumps had previously been tried and failed in this severe environment. The flow and head are fairly low, but the fluid weighs 13560 kg/m^3 . The first magnetic drive pumps were initially installed in this application

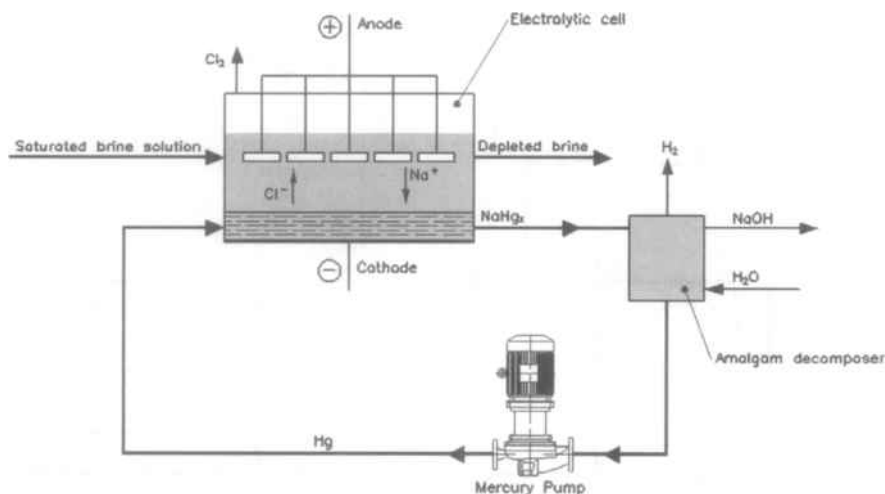


Figure 16.18 Mercury cell process schematic
Courtesy of Courtesy of Dickow Pumpen KG



Figure 16.19 Section through the magnetic drive pump
Courtesy of Courtesy of Dickow Pumpen KG

in early 1998 and have subsequently overcome many of these problems successfully. (See Figure 16.19).

Caustic soda produced by this method is of high purity. On the negative side, the toxic nature of mercury is associated with the greatest potential for adverse environmental and health effects. Strict safety procedures and process controls are followed to prevent workplace exposure and to minimize mercury emissions.

Mercury emissions

Mercury emissions from Chlor-alkali producers have declined significantly over the years. The current contribution of this industry to total natural and anthropogenic mercury emissions is less than 0.1 percent. Western European mercury process plants reduced mercury emissions from 26.60 g/ metric tonne in 1977 to 1.25 g/ metric tonne in 2000. US producers made a voluntary commitment to the US Environmental Protection Agency to reduce mercury emissions by 50%.

Mercury cell use has declined since 1972, and now represents less than 20 percent of all worldwide production. It is claimed that in the future there will be fewer and fewer mercury cells operating as the older plants are shut down or converted to membrane cells. It is also claimed that European and North American producers are committed to not building any new mercury cell facilities.

Magnetic drive pumps are currently used in many mercury cell plants operating in North America.

Application courtesy of Dickow Pumpen KG

16.6 Domestic heating systems and pumps

Introduction

The piping and instrumentation around the boiler of a typical domestic central heating system are shown in Figure 16.20. The functions of the constituent components of the system are described.

Boiler

The outlet water temperature from the boiler, set at 90°C, is controlled by an integral thermostat which switches the burner on and off.

Expansion vessel

The expansion vessel accommodates changes of volume of the water and maintains a suitable static head in the system in order to avoid cavitation.

Pipes

Pipes are sized in accordance with the pressure drop and the length of the runs. Pipes are normally copper but steel and stainless steel are also used on occasions. Figure 16.20 shows a double pipe system. Single pipe systems are also used but are more difficult to control.

Radiators

These transfer heat from the hot water to the air in the rooms. Suitable distribution of water flow to the radiators is ensured by means of adjustable throttle valves. Fitting thermostatic control valves to the radiators removes the need for preset throttle valves.

Hot water for taps

An independent water circuit is shown for heating domestic hot water for taps. In some designs, the hot water heating is controlled by an electrically driven diverter valve which changes the priority between hot water heating and room heating.

Mixing valve

Regulates the system water temperature by admitting return water. Often located close to, or built into, the boiler.

Clock-thermostat

Reduces the system water temperature at night or at other desired times when a lower room temperature is acceptable. This can be used for energy conservation through the day when the house is not occupied or as frost protection.

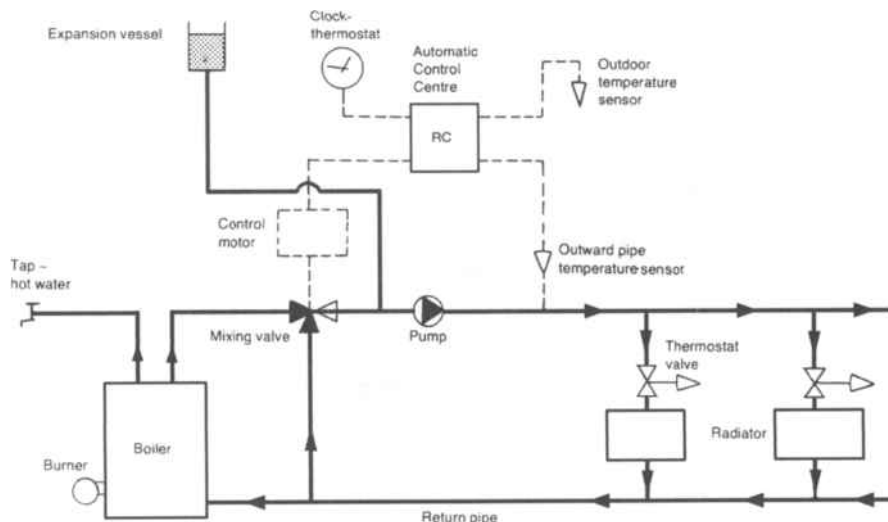


Figure 16.20 Boiler and controls for domestic central heating

Automatic control centre

Receives signals from the system water temperature and outdoor temperature sensors. Adjusts the thermal load via the mixing valve by a suitable outdoor pipeline temperature as a function of the outdoor temperature. In this way a more even room temperature is obtained and a lowering of the room temperature at night is made possible.

Thermostat valves

Valves throttle the flow to radiators depending upon the local air temperature, thereby permitting individual room temperature adjustment. They also make allowance for other heat sources, from the sun, electric sources, etc.

Design temperature

Forward pipe temperature approximately 80 °C, return pipe approximately 60°, $\Delta t = 20$ °C. The heat required is adjusted in accordance with outdoor temperature.

Pump

The pump circulates a flow which is nearly constant depending upon the pressure drop created by the thermostatic valves and the mixing valve. Pumps can be too large and can cause flow noise. This is avoided by using pumps with built-in flow adjustment by throttling or by-pass or speed control. Wet rotor pumps are often chosen to avoid shaft seals.

Pitfalls

Check the rotation of three phase pumps when installing. The ingress of contaminants from pipes during installation and corrosion products from boiler and pipes causes wear to the pump bearings. The system must be heated up and drained before finally put into operation. The system should be cleaned out regularly with chemical dosing. In the summer when the system is not used, the pump should be run regularly to prevent any sediment collecting and causing possible damage to the pump.

16.7 Adjustable jet pump

Introduction

Many thousands of adjustable jet pumps have been installed in heating plants, mainly in Europe.

Description

Figure 16.21 shows an infinitely variable jet pump with corresponding pressure and velocity distributions. Regulation is by means of an adjustment needle valve. In the Figure:

- G1 = motive mass flow with inlet pressure P1
- G2 = pumped mass flow with inlet pressure P2
- G3 = G1 + G2 with outlet pressure P3

Two central heating schemes are shown in Figure 16.22. When comparing the upper conventional system with the lower using the adjustable jet pump, it can be seen that the jet pump replaces both the mixing valve and the circulation pump. In order to drive the jet pump the necessary pressure must be generated elsewhere. Both plants can be controlled by the outdoor temperature and can be fitted with a timer to provide for reduced indoor temperatures at night.

Regulation

For varying heating requirements caused by variations in outdoor temperature, the setting of the adjustment needle valve is changed. This results in changes in the mixing ratio G2/G1, the temperatures t2 and t3 and the flow G3 through the radiator circuit. In a comparison with the conventional system at reduced heating requirements the result is:

- Lower return pipe temperature

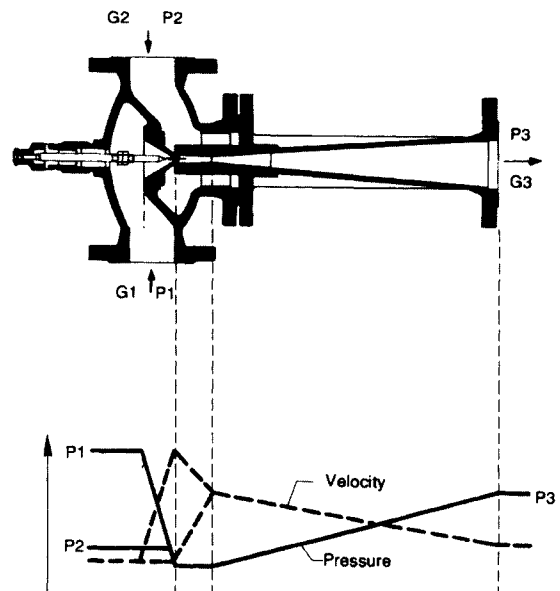


Figure 16.21 Cross-sectional arrangement and pressure/velocity distribution for a jet pump

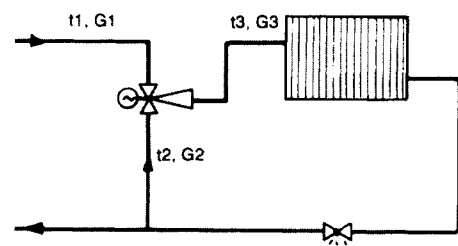
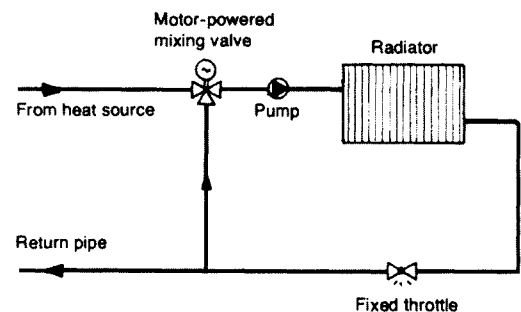


Figure 16.22 Central heating schemes — conventional (upper) and with jet pump (lower)

- Reduced flow in the radiator circuit
- Greater temperature difference in t3 and t2

System properties

The reduced flow in the radiator circuit results in reduced pressure drop and thereby in reduced pump energy consumption. In the case of larger heating systems the necessary pressure for the jet pump is supplied by a centrally located carefully sized centrifugal pump. The adjustable jet pump can in theory replace the circulation pump and the mixing valve in all existing sub-circuits of the heating system.

16.8 Updating of water supply for industrial use

Figure 16.23 shows a schematic arrangement of a water extraction plant feeding a booster station after modification to variable speed control.

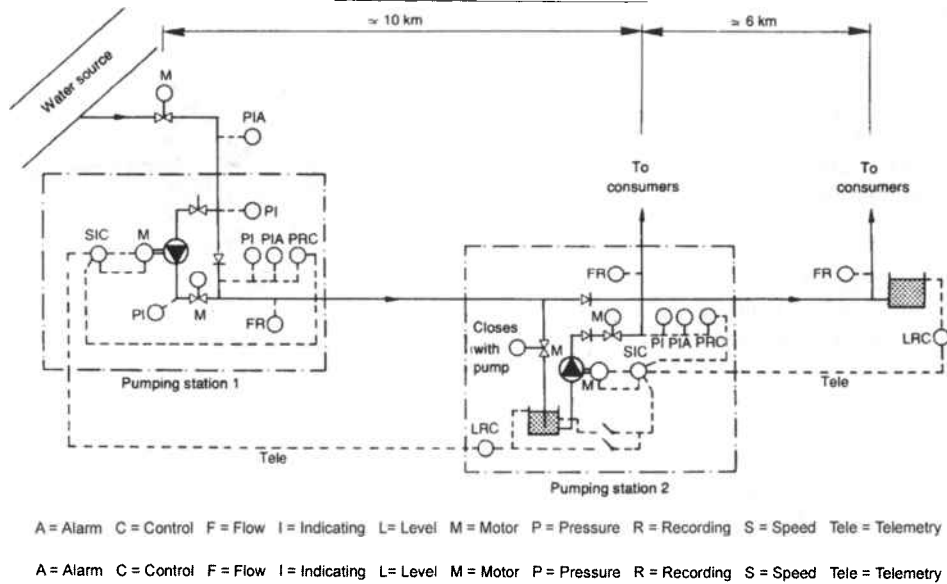


Figure 16.23 Schematic arrangement of modernised water supply system

Control before updating

Before modernisation both pumps were driven at a constant speed. The flow was controlled by a manual throttle valve, set on the basis of experience, at various times. Variations in water consumption led to varying throttle valve positions and energy wastage. The system could not react to unexpected changes in demand.

Control after updating

After modernisation both pumps were driven at variable speeds by thyristor controlled DC motors. The speed of the pump in Pumping station 1 is controlled by the water level in the sump at Pumping station 2. The speed of the pump in Pumping station 2 is controlled by the water level in a storage tower at the end of the main distribution pipeline. Throttling is no longer required.

The speed of the pumps cannot be regulated to zero. In the case of extremely low water demand the pumps are switched off. The storage volumes in the sump and storage tower being adequate to prevent rapid on-off cycling.

Alternative control

In the event of faulty transmission of remote control signals it is possible to control the speed of the pumps in accordance with the pressure on the discharge side of the respective pumps. If Pumping Station 1 is out of service, Pumping Station 2 can be controlled by the level in the sump at the station. If Pumping Station 2 is out of service, Pumping Station 1 can pump directly to the storage tower at slightly lower flow rates.

System details

Installed motor capacity 960 kW per pumping station.

Flow approximately 3400 m³/h

Diameter of pipelines 800 mm

Operational results after updating

Modernisation has resulted in a reduction in water pumping for the industrial plant of about 40%, i.e. water savings of about 2160 m³/h. The consumption of electricity has been reduced by about 60% corresponding to energy savings of about 10 GWh per year.

16.9 Economic aspects of energy utilisation

Choice of pumps

When selecting circulation pumps for heating systems, due consideration must be given not only to the relative merits of a

particular type of pump, its efficiency and serviceability etc., but also to the overall economy of the heating system as a whole.

Depending upon the size and type of heating system and the relative costs of heating fuel and electrical power sources, it can be shown that, in spite of its lower efficiency, a wet rotor circulation pump can be more economical in terms of total energy costs, than a dry motor pump.

In most instances the final choice of circulation pump depends upon factors other than optimum energy utilisation. In small and medium plants it is advantageous to use wet rotor circulation pumps, Figure 16.24, since they can, to a large extent, operate without service or maintenance. In large plants, which are often supervised by operating personnel, it is usual to utilise



Figure 16.24 Wet rotor circulation pump, direct coupled in-line version



Figure 16.25 Circulation pump with standard motor and seal, single and twin head version

pumps driven by standard motors, dry motor pumps, Figure 16.25, because of their higher efficiency.

In borderline cases between small and large plants it may be necessary to carry out a comparative evaluation of the two types. In this comparison the question of total energy utilisation should directly influence the choice of pump. The dry pump motor losses are radiated and convected to the surrounding air, whilst the wet pump motor losses are almost entirely given up to the heating system media.

The following describes methods of evaluating the economic aspects related to the use of wet or dry motor pumps respectively — two extreme cases.

Definitions and assumptions

When comparing wet rotor and dry motor pumps, it is usual to refer to pump efficiency, η_P , which is defined as the relationship between the input and output power, equation 16.1, the difference in the two values being equal to the pump losses, equation 16.2.

For pumps, the input energy is defined as the required shaft input power, P , or as the input electrical power supplied from the electric supply system for the pump unit as a whole, the motor losses being also taken into account. The output is usually defined as work done, P_q , equation 16.3.

The motor efficiency is defined as mechanical power output divided by electrical power output, the difference between the two being mechanical and electrical losses, see equation 16.4. In close coupled pumps the pump power input and the motor power output must be equal.

The overall efficiency of the pump unit, η_U , is obtained by multiplying the motor efficiency, η_M by the pump efficiency, η_P , equation 16.5.

All the losses in a pump unit, and even pump work is converted into heat and can be utilised by the heating system. The pump output power, P_q , is dissipated by friction which results in heat. The pump losses, P_{VP} , are converted into heat within the pump. If the pump unit is mounted within the heated space, the motor losses, P_{VM} , are given up directly to the surroundings.

In order to make a proper comparison between various types of pump unit, account must be taken of the economic relationship of the heating fuel and the electrical energy supplied to the pump motor. In the following analysis the term “economic efficiency”, η_E , is used to represent the relationship between the output and input energy, with due consideration to the specific energy costs of the losses.

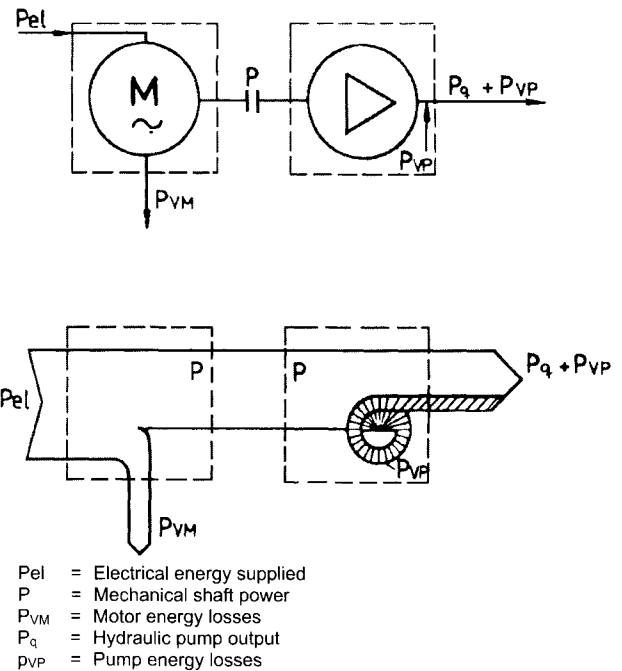
The cost per heat unit extracted from the fuel, allowing for the efficiency of the heating system, η_H , is defined by “a” in equation 16.6 and the cost for electrical energy supplied by “b” in equation 16.7, both values in currency/kJ.

Standard motor pump units

Figure 16.26 illustrates the energy flow for a pump unit with a standard motor and seal. The motor takes energy from the electric supply system and supplies the pump with mechanical energy via the shaft coupling. The motor energy losses are given up to the surroundings, see equation 16.4.

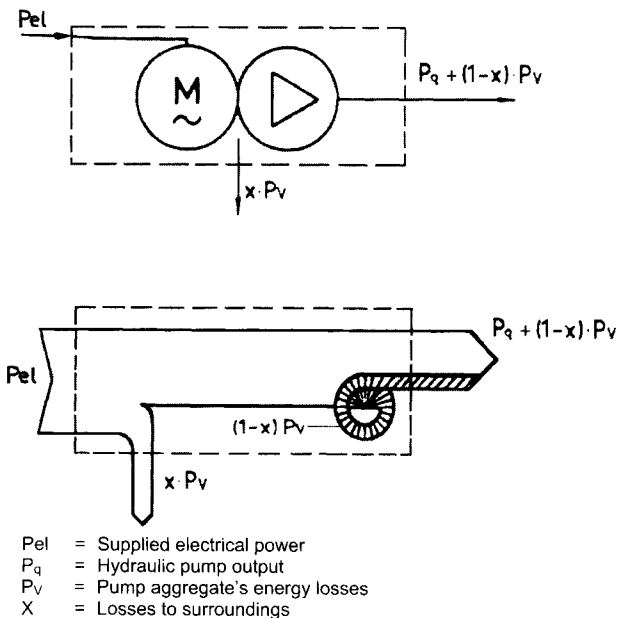
The mechanical power is converted into hydraulic energy, equation 16.3, and the pump losses, equation 16.8, are converted into heat and transferred to the liquid.

When calculating the “economic efficiency” of a heating system using a “dry” pump unit, then the unit efficiency must include the pump losses, equation 16.9. The energy costs related to the pump losses being the only losses which can be usefully utilised by the heating system.



See equations for symbol explanations

Figure 16.26 Energy flow diagram for a standard motor pump unit



See equations for symbol explanations

Figure 16.27 Energy flow diagram for a wet rotor motor pump unit

Wet rotor motor pump units

Figure 16.27 illustrates the energy flow for a pump unit with a wet rotor motor. A large proportion of the energy consumed by the motor is utilised by the heating system.

The greater part of the motor heat losses and the pump friction losses are utilised by the plant as additional heat. The heat losses dissipated to the surroundings are negligible and need not, therefore, be included in the calculations. The “economic efficiency” of a wet rotor motor pump unit is obtained by considering the pump unit efficiency and the value of the additional heat supplied, equation 16.10.

Equations

$$\eta_P = \frac{\text{pump output power}}{\text{pump input power}} = \frac{P_q}{P} \quad \text{Equ 16.1}$$

$$P_{VP} = \text{pump power input} - \text{pump power output}$$

$$= P - P_q$$

Equ 16.2

which can be written as

where:

 η_P = pump efficiency (decimal) P_q = pump output power (W) P_{VP} = pump losses (W) P = pump input power (W) P_q = work done

$$P_q = Q \cdot \Delta H \cdot \rho \cdot g$$

Equ 16.3

where:

 Q = flow (m³/s) ΔH = differential head (m) ρ = liquid density (kg/m³) g = gravitational acceleration (9.81 m/s²)Motor energy losses η_M :

$$\eta_M = \frac{P_{el} - P_{VM}}{P_{el}}$$

Equ 16.4

where:

 μ_M = motor efficiency (decimal) P_{el} = electric power input (W) P_{VM} = motor losses (W)

$$\eta_U = \eta_P \cdot \eta_M$$

Equ 16.5

where:

 η_U = unit overall efficiency (decimal)

$$a = \frac{\text{heating fuel cost}}{\text{calorific value} \cdot \eta_H}$$

Equ 16.6

$$b = \frac{\text{electrical energy cost}}{3600}$$

Equ 16.7

where:

 a = heating fuel energy cost (currency/kJ) b = electrical energy cost (currency/kJ) η_H = heating system efficiency (decimal)Pump losses P_{VP} are:

$$P_{VP} = Q \cdot \rho \cdot C_p \cdot \Delta t$$

Equ 16.8

where:

 C_p = specific heat of liquid (kJ/kg/K) Δt = temperature rise across pump (°C)

$$\eta_{EDry} = \frac{P_q + ((P_{el} - P_q - P_{VM}) \cdot a/b)}{P_{el}}$$

substituting $(P_{el} - P)$ for P_{VM}

we obtain

$$\eta_{EDry} = \frac{P_q + ((P_{el} - P_q - (P_{el} - P)) \cdot a/b)}{P_{el}}$$

which can be simplified to

$$\eta_{EDry} = \frac{P_q + ((P - P_q) \cdot a/b)}{P_{el}}$$

$$\eta_{EDry} = \eta_{UDry} + ((\eta_{MDry} - \eta_{UDry}) \cdot a/b)$$

Equ 16.9

where:

 η_{EDry} = economic efficiency for a pump unit with a standard motor (decimal)

$$\eta_{EWet} = \frac{P_{el} + ((1 - x) \cdot P_v \cdot a/b)}{P_{el}}$$

which can be rewritten as

$$\eta_{EWet} = \eta_{UWet} + ((1 - x - \eta_{UWet} + x \cdot \eta_{UWet}) \cdot a/b)$$

realising

$$x \cdot \eta_{UWet} \approx 0.03$$

it is considered negligible

$$\therefore \eta_{EWet} = \eta_{UWet} + ((1 - \eta_{UWet} - x) \cdot a/b)$$

Equ 16.10

 η_{EWet} = economic efficiency for a pump unit with a wet rotor motor (decimal)

$$a/b_{crit} = \frac{\eta_{UDry} - \eta_{UWet}}{1 - \eta_{UWet} - x - \eta_{MDry} + \eta_{UDry}}$$

Equ 16.11

$$\text{oil cost} = \text{calorific value} \cdot \rho \cdot a/b_{crit} \cdot b \cdot \eta_H$$

Equ 16.12

where:

oil cost (currency/m³)

calorific value (kJ/kg)

 ρ = density (kg/m³) a/b_{crit} = value from equation 16.11 (decimal) b = electrical energy cost (currency/kJ) η_H = heating system efficiency (decimal)

Comparison

Two extreme cases have been chosen to demonstrate the relative differences in total economy when considering similar heating systems.

1. Very low fuel costs and high electricity costs, i.e. the ratio a/b approaching zero,
2. The cost of fuel and the cost of electricity is approximately the same, i.e. the ratio a/b approaching unity.

The expression "economic efficiency", defined previously, is used here to calculate the effect of energy prices and should not be considered as a value of efficiency in the normal sense.

Case 1. In for example, the Netherlands, where gas is relatively cheap and electricity is relatively expensive, the situation is very similar to 1. above.

According to equations 16.9 and 16.10 and with $a/b = 0$ the "economic efficiency" for both dry and wet rotor motor pump units will be equal to the unit efficiency, η_U .

Since the unit efficiency for a dry motor pump is always higher than for a wet rotor motor pump, then it follows that the "economic efficiency" for a dry motor pump is always greater than for a wet rotor motor pump, i.e.

$$\eta_{EDry} > \eta_{EWet}$$

Case 2. In Sweden, for example, electrical energy has been relatively cheap by international standards. The relationship between fuel and electrical energy costs, a/b , is almost unity, if the normal heating system efficiency for larger installations of

0.75 to 0.80 is taken into account. This is very similar to 2. above.

If a/b is 1, then from equation 16.9 for dry motor pump units, the "economic efficiency" is equal to the motor efficiency. For wet rotor motor pump units operating under the same conditions, $a/b = 1 - x$, where "x" is the losses to the surroundings, then the "economic efficiency" is determined by applying equation 16.10.

Measurements have shown that the losses "x" to the surroundings are normally between 4 and 7%, for wet rotor pumps with motors up to 2.2 kW, which is less than the corresponding dry motor pump losses of about 20%.

It can therefore be concluded that, for heating systems in these circumstances, better running economy will be achieved using wet motor circulation pumps than by using dry motor pumps, i.e.

$$\eta_{EW\alpha} > \eta_{EDry}$$

Conclusions

The heat output of a heating plant is provided by the heat extracted from the fuel and the power supplied to the circulating pump.

The electrical energy contribution, although being relatively small, is important when considering the optimum economy of the complete heating system.

A comparison of heating system energy costs for similar systems in different countries shows that in countries like Sweden where electrical energy is relatively inexpensive, the ratio a/b approaches 1 thus making wet rotor motor circulation pumps, despite their lower efficiency, more economical in service than dry motor pumps.

In countries such as the Netherlands where electricity is more expensive, the ratio a/b approaches 0 and dry motor circulation pumps are more "economically efficient".

16.10 Pumping of delicate solids – food and live fish

Introduction

Screw centrifugal impeller pumps are being used to transport even the most perishable of foods, for example oranges, apples, cranberries, bean sprouts, beans, peas and mushrooms around food processing plants (See Figure 16.28).

For many years also they have been used in fish farms for the transfer of live fish, grading or tanker-loading duties; helping to reduce and eliminate the damage and high labour costs incurred with the more traditional manual methods previously employed. See Figure 16.29.



Figure 16.28 Food processing of mushrooms
Courtesy of Hidrostat Ltd

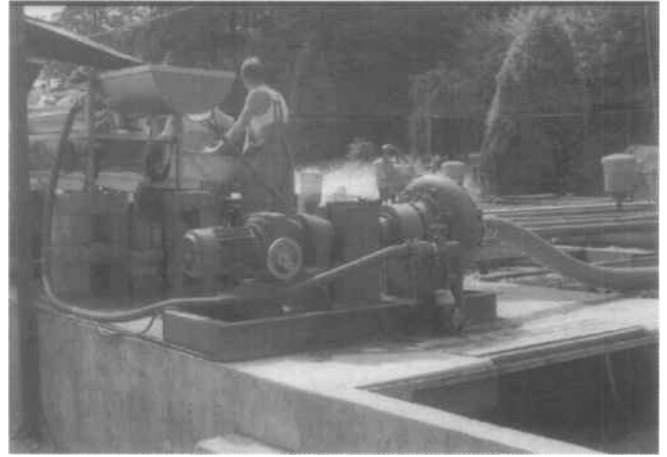


Figure 16.29 Handling live trout
Courtesy of Hidrostat Ltd

Pumping food

The pump and its associated pipework system is particularly beneficial where space is limited or where there is a need to transport large volumes over long distances, or on complicated routes, where the alternative is transferring produce between numbers of different conveyor belts. See Figure 16.30.

One of the most important requirements of equipment used in food processing is of course, an ability to handle produce gently and this is where screw centrifugal impeller pumps have an advantage, being originally designed to pump live fish. As a consequence, the pump is renowned for its ability to transport even the most delicate of materials without damage.

The pump is characterised by several unique features including an ability to handle delicate solids without damage and viscous materials at a low shear rate. This allows the transportation of even the most fragile materials over a wide range of pumping rates. It has a very smooth hydraulic path, large free passages and high efficiencies which produces low re-circulation of the liquid within the pump. This in turn results in the use of smaller electric motors, lower power costs and reduced maintenance costs.

Cleaning the pump provides minimal disruption to the factory processes; this is achieved by flushing with clean water or pumping a cleaning agent through the pipelines. Because the pump system is easier to clean it is more hygienic. As well as promoting rapid and effective cleaning, the fact that the pipework is enclosed reduces the danger of dirt falling into the

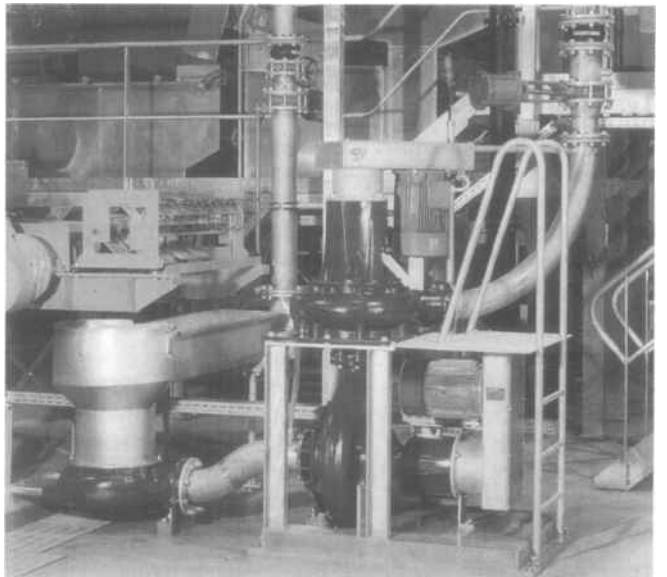


Figure 16.30 Typical food processing plant
Courtesy of Hidrostat Ltd



Figure 16.31 The pumping of live fish
Courtesy of Hidrostal Ltd

system or indeed any produce falling out. This has the double benefit of increased productivity and promotes a safer, cleaner and more pleasant working environment.

Pumping live fish

In this application, pumps are supplied as trolley or skid mounted units, with a variety of drive options. For duties where a suction lift is required the unit is easily primed by use of a fitted high capacity, hand-operated diaphragm pump.

A variable speed drive arrangement is incorporated to ensure that the pump speed/duty can be tailored to enable optimum performance for gentle, damage free handling to be achieved. Units can be available in a range of pump sizes and configurations suitable for handling a wide range of fish sizes from fingerlings up to full grown salmon. See Figure 16.31.

Application courtesy of Hidrostal Ltd

16.11 Submersible sump pumps for construction projects

Introduction

Electrically driven sump pumps are readily available from stock in various sizes from 1 kW up to 20 kW both for sale and leasing. Standard pumps of up to 60 kW can usually be supplied on short delivery from the manufacturer. Pumping of this kind is primarily intended for temporary drainage work for building and construction activities on site. In the case of major construction projects, the installations may be of a permanent nature. Pumps constructed of aluminium may be restricted to certain water grades.

Types of drainage

The nature of the drainage is characterised by the type of civil engineering activity. Industrial and housing construction does not normally require involvement with rivers or lakes and drainage is therefore mainly concerned with groundwater, storm and rainwater etc. The drainage period is short in relation to the construction period and the pumping requirement is often of a limited nature. Sizes 1 to 5 kW easily meet the requirements.

Harbour and bridge construction works involve their own type of drainage characterised by large flows and moderate to low delivery heads. Discharge pipes can often be short, further limiting the total delivery head. Typical of this type is drainage and drying out of coffer dams. This type of draining is often simple to plan and supervise. Pumps of low head of 10 to 30 kW are required to yield flows of 180 to 600 m³/h.

The greatest pump investment, in percentage terms of the total costs, is often required by hydro-electric power plant construction works and mining. The investment is particularly large in

the case of long deep tunnel sections. Sophisticated dewatering techniques involving severe demands on planning and maintenance are mainly concerned in the case of tunnel driving.

A typical four year power plant construction project illustrates the implications for pump choice.

General plant information

Headrace tunnel 4200 m long, area 24 m²

Two transport tunnels, each 400 m, area 15 m²

Tailrace tunnel 5600 m, area 30 m²

Three transport tunnels, each 350 m, area 15 m²

Maximum head 62 m

Differences in level in the transport tunnels between ground level, open excavation, and lowest level, i.e. at entrance to main tunnel.

Tunnel 1 41 m

Tunnel 2 40 m

Tunnel 3 34 m

Tunnel 4; 5 36 m

The transport tunnels are driven at a gradient of 1:10.

Transport tunnel 1 may be used as typical for drainage techniques for tunnels and rock chambers.

Pump sizing data

Total estimated flow of water Q_b comprises:

- Estimated leakage of water due to poor rock
- Estimated penetration of melt and rain water through open excavation
- Estimated amount of drilling water

Total difference in elevation levels between lowest water course and discharge pipe outlet = H_{stat}

Total length of pump pipeline = L_{tot}

Pipe details: quick-coupling pipes 100 mm diameter and 150 mm diameter.

Two drilling units are used with a total water requirement of 8.4 m³/h when in operation. Leakage from the rock is estimated to be 6 m³/h and melt/rain water to be 12 m³/h, $Q_b = 26.4$ m³/h. A safety margin added to ensure pumps could always cope with water flow brought the flow to $Q_{max} = 36$ m³/h.

An estimate of the pressure loss in 100 mm and 150 mm pipes respectively with a design flow of 36 m³/h indicates 100 mm pipe to be acceptable. Pressure loss $H_f = 9$ m. Total differential head:

$$H_{stat} + H_f = 41 + 9 = 50 \text{ m}$$

The drainage is divided into two phases.

Driving of the tunnel from tunnel face and open excavation to level at -41 m at the main tunnel. During this phase, use is made of pumps capable of pumping full flow but about half the differential head, i.e. 36 m³/h x 25 m. The intention is that the pump should be light and well-matched to the actual duty. When about half of the length of the tunnel has been driven, i.e. about 200 m and $H_{stat} = 20.5$ m, the first pumping station can be constructed and made permanent for the entire construction phase.

After the transport tunnel has been put to use, water flows from the main tunnel now under construction. Admittedly, the 8.4 m³/h drilling water from the transport tunnel itself has now been eliminated, but the four units in the main tunnel produce 16.8 m³/h and this must be added to the leakage from the main tunnel.

A rough estimate indicates that Q_b through the transport tunnel will be 42 m³/h.

This means that:

$$Q_b = 42 \text{ m}^3/\text{h}$$

$$H_{\text{stat}} = 41 \text{ m}$$

$$Q_{\text{max}} \text{ estimated to be } 60 \text{ m}^3/\text{h}$$

Pressure loss H_f then becomes 20 m for 100 mm pipe, which is too high a loss. If the pipe size is changed to 150 mm, H_f at 60 m³/h will be 4 m. Thus:

$$H_{\text{stat}} + H_f = 41 + 4 = 45 \text{ m}$$

This station may be constructed to two designs: a pump chamber blasted out of the rock or a steel pump tank.

The advantage of the steel tank, see Figure 16.32, is that it can be easily moved and can therefore follow the advance of the tunnel downwards. This enables the waste pump on the drilling car to work constantly with the same length of hose and delivery head.

On reaching level -20 m a complete pumping station is established at that level and an additional similarly equipped station follows the working face down to the beginning of the main tunnel at level -41 m.

When the transport tunnel joins up with the main tunnel two options for the continued drainage of the transport tunnel may be considered, Figure 16.33.

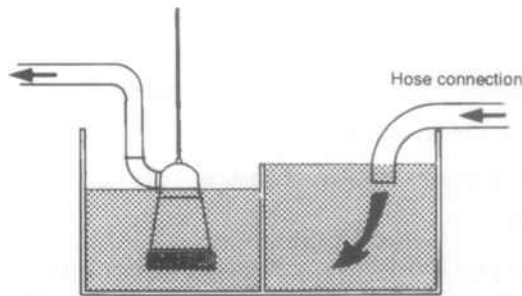


Figure 16.32 Pump station — steel tank option

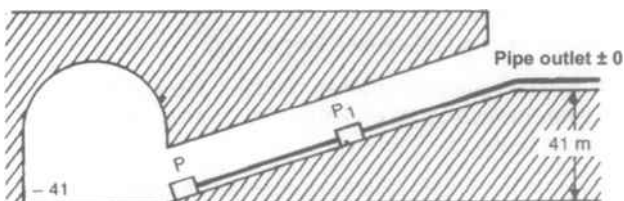
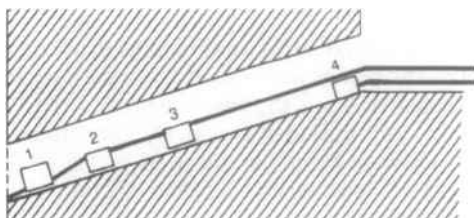


Figure 16.33 Drainage with two pumping stations



1. Drilling car with air-powered diaphragm pump
2. Pumping station with submersible electric pump 60 m³/h x 22.5 m
3. Pumping station with submersible electric pump 60 m³/h x 22.5 m
4. Submersible electric pump for rain and melt water with its own pipe. Size about 30 m³/h x 5 m

Figure 16.34 Drainage with four pumping stations

Option 1 — Retention of two pumping stations each with a total delivery head of 22.5 m and maximum flow of 60 m³/h.

Option 2 — Installation of one central pumping station at level -41 m, the pumping duty then being 60 m³/h x 45 m.

Option 1 is preferable because the pump size used permits greater range of application and reduces the risk of water hammer in the case of power failure. The advantage of Option 2 is that inspection can be limited to a single station.

The total pumping requirement for the transport tunnel until the commencement of Phase 2 is shown in Figure 16.34.

General installation instructions for drainage

Determination of size may be found by:

- Difference in elevation
- Length of pump pipe
- Flow

The difference in elevation between the liquid surface and the pipe outlet is always known. The length of the pump pipe can always be determined.

The flow of water to be pumped can usually only be estimated and this must be done on the basis of experience. When this has been done, the manufacturer's instructions should be consulted, to calculate the pipe friction loss and this added to the difference in elevation.

$$H_{\text{stat}} + H_f = H_{\text{tot}}$$

Flexible pipes

When using hose as a pump pipe, a 20% addition should be made for unavoidable kinks. Use the shortest possible route.

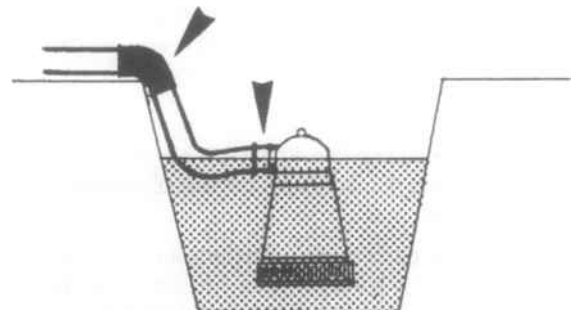


Figure 16.35 Correct routing of flexible pipes

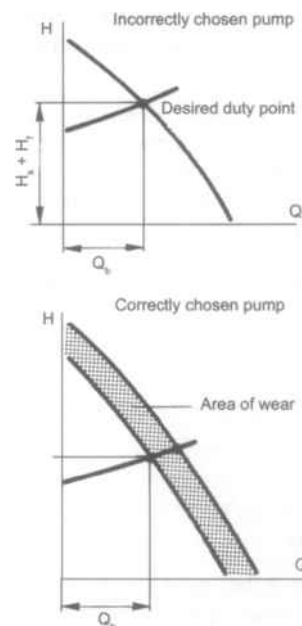


Figure 16.36 Pump curves corrected for wear

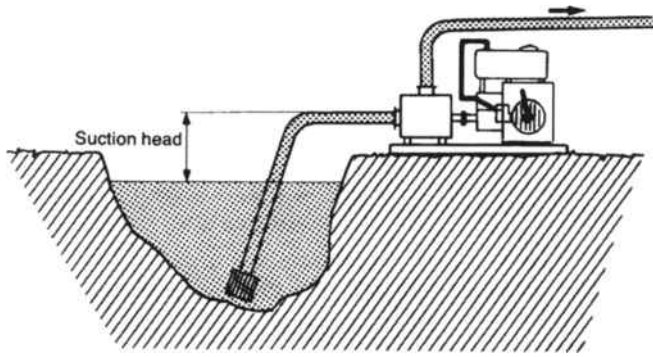


Figure 16.37 Skid mounted self-priming pump

In open shafts and pits always place the delivery connection at right angles to the pump shaft to avoid kinks.

In the case of sharp edges, e.g. rebates, use pipe bends and connector pipes. See Figure 16.35.

Always select a pump giving consideration to the wear factor. This is especially important in the case of the pumping of tunnels. Drilling waste is very abrasive for impellers and rubber components, see Miller Number in Chapter 2, Table 2.13, causing rapid reduction in capacity. See Figure 16.36.

16.12 Use of engine driven self-priming pumps

Pumping unit

Figure 16.37 shows a self-priming site pump with a petrol or diesel engine mounted on a skid, and suction hose with strainer. The discharge hose is normally about 10 m long. Extra lengths can be added when necessary. The skid is fitted with lifting and towing eyes.

Size of pumps

Pumps in good condition can lift 8 m. Table 16.1 indicates the flow ranges of some popular pump sizes at differential heads of between 10 and 20 m.

This type of pump can handle solid particles. It is not a solids handling pump in the sense of solid-liquid mixtures but a rugged pump capable of passing occasional, fairly large solids plus mud and soil. The size of the maximum solid increases with pump size. The mesh of the suction strainer is selected on the basis of the pump inner passage size. In practice it is accepted that all solids capable of passing through the strainer are pumpable.

In the case of a discharge hose which is more than about 30 m long, it is advisable to check the head drop of the hose. This is easily evaluated with the aid of the nomograms in Chapter 3, starting at Figure 3.24. The head drop has the effect of reducing the capacity of the pump.

Suction connection mm	Flow range m ³ /h
40	10 to 20
50	10 to 30
75	20 to 60
100	30 to 100
150	30 to 300
200	30 to 500

Table 16.1 Capacities of popular engine driven pumps

Site installation

Place the pump on a flat, level and if possible rigid pad. Most engines and pumps are splash-lubricated so levelling is quite important. The difference between the water level and the centre-line of the suction connection should not exceed 8 m. The

suction hose should ascend uninterruptedly to the pump. Position the suction strainer near the bottom without burying it in mud, etc. In the case of small flows the strainer can be placed in a shallow pit approximately 0.5 x 0.5 m.

Pumping

Fill the pump with water through the filler. The volume of water necessary is 2 to 5 litres.

Start up and evacuate the suction pipe. If the time for evacuation exceeds 2 to 3 minutes, there is a fault, e.g. too great a suction lift, leaky suction hose, worn-out pump, etc.

As the level in the pit reduces, move the strainer to greater depths. As the suction lift increases the flow will reduce. If there is plenty of water, it is only necessary to check the pump every quarter of an hour. A full fuel tank usually suffices for 2 to 3 hours, but try to avoid running at very low fuel levels. Sediment in the fuel tank can block filters and injectors. If fuel runs out, the fuel system may have to be vented and primed. If the water flow is small, reduce the engine speed to a suitable level.

Each day when pumping is finished, wash the pump and suction strainer out with clean water. Dried mud and setting concrete can seriously affect performance. In cold weather, drain the pump completely each night to prevent freezing. Before storing between jobs, protect in accordance with the manufacturer's instructions.

State when purchasing or hiring:

- Flow and corresponding delivery head
- Suction lift
- Maximum particle size
- Desired power source, e.g. 4-stroke petrol engine
- Maximum weight which can be handled at site
- Maximum noise level
- Requirements for skids or trailers

Pitfalls

- Leaky suction hose results in reduced pump performance. An air leak on the suction side can be detected by placing the discharge hose under water. Air bubbles indicate air leakage in the suction hose or the pump.
- Petrol-oil mixtures should only be used for two-stroke engines. Wrong fuel causes long delays.
- A blocked suction strainer reduces the capacity of the pump. In such cases check the strainer regularly and clean out as required.
- Kinks in the hoses cause unnecessary throttling.

16.13 Cargo pumps for tankers

Large tankers for crude oil

Large tankers are fitted with a small number of oil cargo pumps, usually four. The pumps are located in a separate pump room. The cargo space on board the vessel is divided into 10 to 15 individual tanks. With the aid of a relatively complicated pipe system every individual pump can be used to unload any of the tanks. Figure 16.38 shows a simplified diagram of how an oil cargo pump system works.

The suction pipe to every tank is connected to a suction funnel close to the bottom of the tank so that the tank can be completely emptied.

The separator tank, which is connected to a vacuum unit, separates gases drawn into the suction funnel during the final stage of unloading.

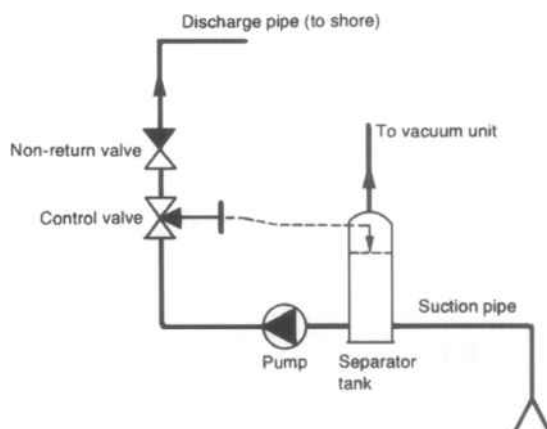


Figure 16.38 Simplified cargo pump system

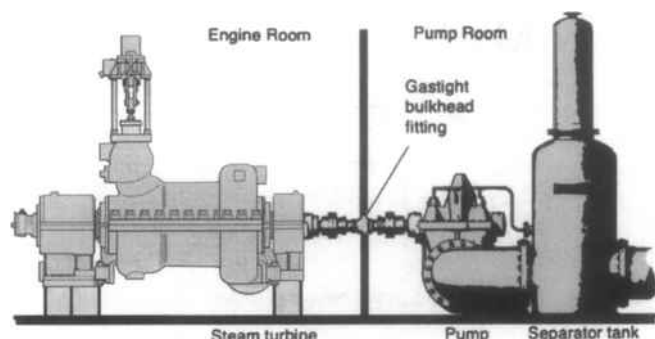


Figure 16.39 General arrangement of steam turbine driven cargo pump

The pump is normally driven by a steam turbine, but electric motors can also be used. Due to the risk of fire or explosion due to the gases given off from the crude oil, the pump driver must not be located in the pump room. Figure 16.39 illustrates a horizontal shaft pump installation.

The control valve is used to reduce the flow during the final unloading stage, which is necessary to ensure the tank is completely emptied. The valve is automatically controlled by the level in the separator tank.

The non-return valve prevents oil from flowing backwards through the pump when unloading is stopped.

The bulkhead acts as a firewall between the two compartments. A spacer coupling is used with a mechanical seal to prevent gas leakage.

The pumps are normally sized to unload the vessel completely in about 24 hours. The delivery head required to pump oil to the onshore terminal is 120 to 180 m. This results in large pumps with heavy power consumption, up to say 7 MW per pump on the largest vessels. Oil cargo pumps are also used for the loading and unloading of water ballast.

The risk of explosion makes it essential that all equipment capable of generating sparks must be excluded from the pump room and the tank spaces. Pumps should be fitted with mechanical seals, since stuffing boxes can become overheated.

During installation, allowance must be made for the movements which take place in the hull. The shaft coupling should be able to absorb minor misalignments between pump and driver.

Smaller tankers for finished products

A characteristic of vessels of this type is their ability to transport a great number of different kinds of liquid cargoes. The cargo space in smaller tankers is also divided into small tanks, the number varying in relation to the design and size of the vessel. As the cargo often consists of a number of different liquids which must not be mixed, a common unloading system cannot

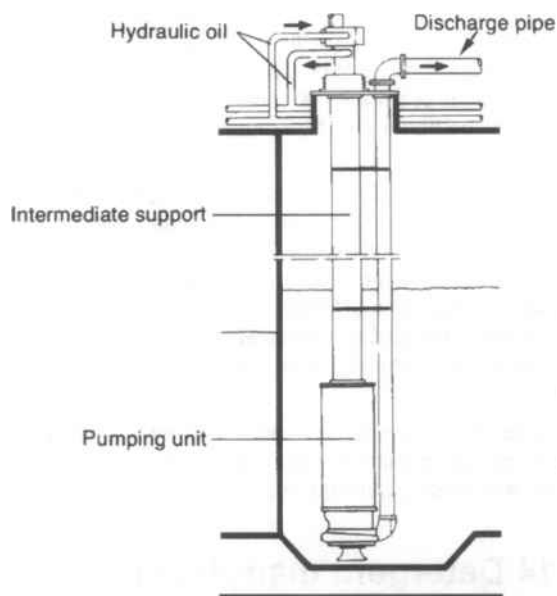


Figure 16.40 Hydraulically driven vertical submersible pump

be used. Instead every tank is provided with a pump of its own, which, bearing in mind the risk of explosion, should be hydraulically powered. Also, hydraulic equipment can be easier to protect against the ravages of a marine environment. In order to simplify installation, the pumping unit is submersed in the liquid. The outline drawing in Figure 16.40 shows the pump installation in a tank.

The pumping unit consists of a centrifugal pump and a hydraulic motor. The suction connection of the pump is bellmouthed and its entrance is close to the bottom of the tank. The capacity of the pump is determined by the volume of the tank. The delivery head is 70 to 150 m.

The delivery pipe and intermediate support or column are cross braced to each other to increase rigidity and reduce vibration. On larger vessels of this kind the distance between the deck and the bottom of the tank is about 15m. In addition to feed and return pipes for hydraulic oil, the intermediate support also contains pipes for sealing liquid.

A constant flow valve maintains the flow of oil to the hydraulic motor, which means that the pump operates at a constant speed independently of the load. The hydraulic motor also contains devices for the remote control of the pump speed. The pumping unit is supplied with hydraulic oil from a power pack which can supply oil to several pumps. The oil pressure in the hydraulic motor feed pipe is normally 160 to 240 barg.

Since the cargo may consist of highly corrosive media, the material of parts in contact with liquids must be given special consideration. The sealing of the pump shaft, which must function in liquids with varying properties, also deserves special attention.

The breakdown of a pump with a tank full of liquid raises difficulties with respect to rapid repair. For such eventualities portable pumps must be available for emptying and flushing out tanks.

LNG carriers

Considerable quantities of LNG are transported from producers to consumers. LNG usually consists mostly of methane so the liquified gas must be stored at temperatures around -160 °C at atmospheric pressure. The material requirements for operating at such low temperatures are well known. The main problem with pumping such cold liquids is ensuring the pump unit is cooled sufficiently for the liquid gas to remain liquid.

This problem can be solved by using submerged pumps in the tanks and specially adapted canned motor pumps have been developed. As the complete pump unit is surrounded by the liq-

uid thorough cooling is practically assured. Great care must be taken with the motor connections into its terminal box. Submerged pumps, of the wet pit type have also been used. Double mechanical seals with a suitable barrier liquid, such as propanol or methanol, must be employed.

When spherical storage tanks are mounted on the ship's deck it may not be possible to fit submerged pumps. In these situations, a canned pump built in an external can may be suitable. The external can must be fitted with vapour vents and liquid level controls to ensure the can is cooled and filled properly. Adequate insulation must be applied to the suction pipe and the external can to prevent ambient conditions vaporising the LNG. Very slight temperature rises cause considerable loss of NPSHa.

Pumps for LNG may seem to "rattle" slightly when first started. This can be due to mild cavitation while vapour is clearing. The "rattling" should stop quite quickly; if not, shut-down and investigate.

16.14 Detergent manufacturing systems — pump installations

Introduction

In this example, the finished detergent is manufactured from three raw materials which are mixed in various proportions, depending upon the grade of the finished detergent, before being dispensed into containers of about five or 10 litre capacity. See Figure 16.41.

The raw material tanks are elevated above the pumps to provide plenty of NPIPa. Each tank is fitted with a tapered bottom leading to a central connection which is twice the diameter of the pump suction connection. The manual isolating valves are full-bore quarter turn ball valves.

Pumping the raw material

The pumps used are triple lobe pumps operating at low speed to maintain the volumetric efficiency close to unity. All three pumps operate together controlled by the programmable logic controller PLC, as shown in Figure 16.42. The speeds of the three pumps are adjusted by the PLC, via variable frequency inverters, to conserve the raw material proportions fed to the mixer. After a preset time the three pumps stop and the electri-

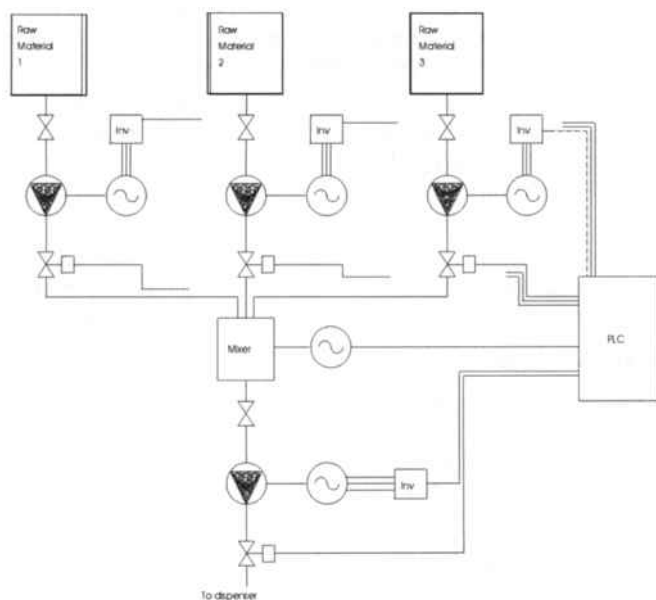


Figure 16.41 Schematic of a typical detergent manufacturing system

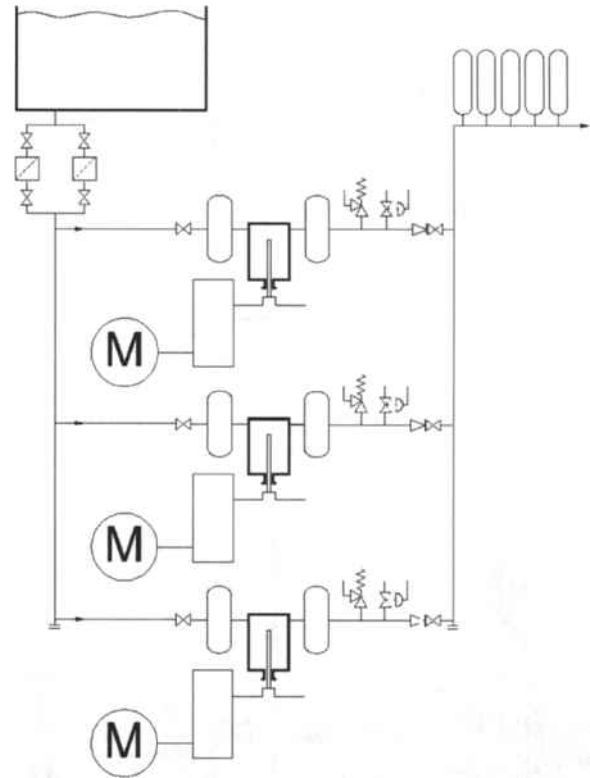


Figure 16.42 Schematic of a typical three pump system

cally actuated valves in the discharge pipes close to prevent "dribbling".

The mixer

Once the mixer has been filled to the required level, the PLC starts the mixer motor which runs for a preset time. The mixer tank also has a tapered bottom and a large connection fitted with a full-bore ball valve.

Finished detergent pump

The finished detergent pump is a low speed triple lobe pump. Volumetric efficiencies close to unity are assured by adequate NPIPa due to low loss pipework. The pump speed is controlled in response to signals from the dispenser.

16.15 High capacity bearings for compact centrifugal pump systems

Introduction

Pump manufacturers are subjected to regular demands to reduce both the cost and the size of the pumping systems that they produce. The main focus of these cost-reductions is on centrifugal pumps because they are the most widely used and



Figure 16.43 Centrifugal pump example
Courtesy of NSK Europe

are the workhorses of industry, providing users with a wide range of flow, volume capacity, and head. They have uses in industries such as pulp and paper, wastewater treatment, steel mills, irrigation, mining and many other demanding environments. Figure 16.43.

The need for compact bearings

The problem for any pump manufacturer designing more compact pump systems is that any reduction in size cannot be at the expense of flow. What this means for key pump components such as bearings is that they, in turn, must become more compact, but at the same time provide higher load capacity to meet new operating demands.

This requires the development of high load capacity, deep-groove ball bearings, resulting in improved basic dynamic load ratings of approximately 10% and fatigue life by around 30%, without any changes to the standard bearing dimensions. These improvements have been achieved via a combination of a new heat treatment process, enlarged ball diameters, and by optimising the interior design of the bearing cages. See Figure 16.44.

Improved life and increased dynamic load ratings

Table 16.2 shows the improvements that are achievable. The Table shows the boundary dimensions and basic dynamic load ratings of both standard and new high capacity bearings. Taking as an example a bearing with 30mm bore x 72mm od: in its standard configuration this bearing has a basic dynamic load rating of 26700 N and a high-load capacity rating of 29, 800 N: an increase in basic dynamic load rating of approximately 12%. As a result of this, bearing fatigue life is increased by approximately 40% for similar load conditions.

Bearing size		Basic dynamic load rating		
Bore diameter (mm)	Outside diameter (mm)	Standard bearings (N)	High-load capacity bearings(N)	Increase in basic dynamic load rating
25	52	14000	15300	9%
25	62	20600	23700	15%
30	62	19500	23300	19%
30	72	26700	29800	12%
35	72	25700	28300	10%
35	80	33500	39500	18%

Table 16.2 Improved life and increased dynamic load ratings

One of the key factors in the longer life of the high-load capacity bearings is a new UR heat treatment process, which is effective in alleviating the stress concentrations that cause surface-originated flaking on bearing material. Surface-originated flaking tends to occur under contaminated lubricating conditions. Stress concentrations develop immediately around indentations formed by foreign particles. The UR heat treatment process prevents this from happening, by increasing the amount of retained austenite within the bearing material. As a result, bear-



Figure 16.44 High capacity bearing
Courtesy of NSK Europe

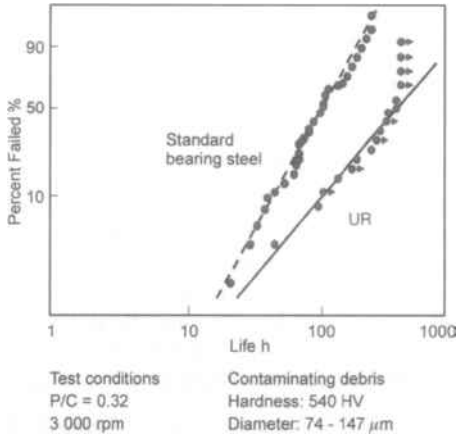


Figure 16.45 Rolling fatigue life of bearing under debris contaminated conditions
Courtesy of NSK Europe

ing durability is significantly improved in contaminated environments. This improvement is illustrated in Figure 16.45. The graph shows that the life of UR treated bearings has improved by twice that of standard bearings operating under conditions of contaminated lubricant.

Another problem in pump bearing technology is that of creep. This is the name given to wear that may occur between the bearing outside surface and housing bore due to low-speed sliding. It is the result of loads becoming excessively high on the driving shaft of a pump. If not addressed, creep causes excessive shaft vibration, which can trigger abnormal oscillation and lead to impeller damage.

Common measures against creep include an interference fit between bearing and housing. For pumps, however, a tight fit is not practical, as it makes pump assembly more difficult and does not allow for additional loading caused by an increase in the shaft length due to heat generation. A solution is to install O-rings into the two grooves on the bearing outer ring. The frictional force of the O-rings helps to prevent the occurrence of creep.

API 610 calls for angular contact ball bearings, with a 40° contact angle, arranged in a back-to-back configuration, and giving a minimum life expectancy of 25,000 hours (3 years) continuous running, or 16,000 hours at maximum radial and axial loads.

It is claimed that these new bearings, by incorporating the one of the strongest machined brass cage available, provide effective reliability in the harshest of applications. They also achieve longer service life, through smoother running, reduced levels of friction and lower temperature rise; the latter as a result of the better heat dissipation of the brass cage material.

It is also claimed that they combine high strength materials technology, ABEC3 (P6) manufacturing tolerances and pump specific axial internal clearances to give high running and shaft positioning accuracy, plus optimum levels of bearing stiffness, as well as load sharing and cooler running. In addition, by the combination of super-finished raceways, low inner ring run-out and high ball grades, it is hoped these will contribute to a reduced level of ball skidding and, hence, smoother operation.

Application courtesy of NSK Europe

16.16 Energy recovery turbines and reverse running centrifugal pumps

Introduction

Pumps are usually purchased to pressurise a liquid. This then enables flow to take place by overcoming resistance in the pip-

ing system. In most cases, the pressure generated is entirely absorbed into the system.

In some cases the pump also has to generate additional pressure to start a process. Boiler feed pumps are one example of this. Here the system frictional resistance might only account for 30% of the generated pressure.

Reverse Osmosis, RO, is another example. Again, the frictional resistance only forms a small percentage of the generated pressure. Most of the pressure is used to stimulate the osmotic process of water purification. About half of the pressurised saline water fails to pass through the RO membrane. This is then discarded. Since this fluid is typically at 45 to 90 barg it must be depressurised before it can be dumped.

In a scrubber plant, impure gas passes through absorbent fluid in the absorber tower. Impurities are absorbed into this carrier fluid. This takes place at relatively high pressure. The fluid then passes to the stripper tower where the impurities are released. To do this the pressure then has to be reduced, or "let-down".

In the refining of oil to gasoline, the product passes through a hydro-cracking process. Again the charge product is pressurised to finalise the process. After reaction, this pressure has to be dissipated before the next part of the process.

In all these cases, liquid has been pressurised to permit some process to take place. It then has to be depressurised for some reason. A simple way of depressurising the fluid is to pass it through an orifice plate. In this approach, all the energy embedded in the liquid is lost as heat and noise.

Another approach is to pass the liquid through a control valve. This is not much different from an orifice plate but at least it is variable.

Energy recovery and its uses

Yet another approach is to pass the fluid through a turbine. This might appear to be an expensive solution. However, it has the advantage that not only is the liquid depressurised, but the energy embedded in the liquid is largely recovered. The value of this power can then be offset against the turbine cost. Experience has shown that this recovered power can repay the cost of the turbine in 9 to 18 months. After that the energy recovered is almost free. On this basis, it is almost irresponsible not to explore all possible uses of energy recovery turbines. How can the energy be used?

- It can be used as the sole power source for another machine
- It can be used to contribute power to another machine and reduce the power consumed by the motor

Reverse running pumps

Conventional turbines are expensive when compared with pumps of the same power. They are not so readily available, nor is the choice so great. The material options are also more limited. For special applications, such as high temperature refinery service the choice is very limited. Fortunately, all forms of centrifugal pump can also be run in reverse to perform as very effective turbines. The disadvantages of commercial turbines are then eliminated. The only shortcoming of reverse running pumps is that their efficiency is lower than a true turbine. However, this is typically only two or three per cent and hardly impacts on the pay-back period. The notation of reverse running pump is as shown in Figure 16.46.

One apparent disadvantage of any turbine is that it needs some form of speed control. Fortunately this can easily be overcome in most cases. This depends upon the turbine being connected into a train that also utilises an electric motor. Electric motors lock into the mains frequency and act as excellent governors. This establishes the speed control the turbine needs.

Fundamentals

The performance characteristics of centrifugal pumps are well known. Those for a turbine are less well known. They are compared below.

Figure 16.47 shows typical pump performance characteristics. Generated pressure decreases as pump flow increases. On the other hand, absorbed power increases with flow.

Figure 16.48 shows the characteristics of a pump used as a turbine, i.e. the flow direction and direction of rotation are reversed but the pressure differential is the same. Note that the differential pressure increases as the flow increases. Also that the recovered power increases with flow. However, below a certain flow, the turbine actually absorbs power.

Figure 16.49 shows the most popular way of connecting a pump and energy recovery turbine. The clutch is optional and its effect is shown by referring to Figures 16.48 and 16.50.

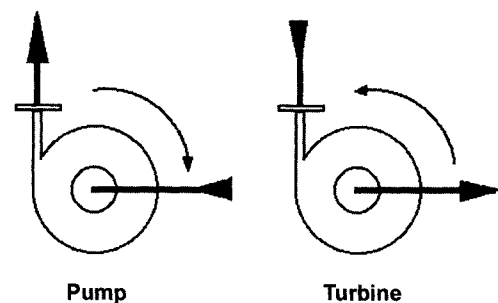


Figure 16.46 Schematic notation of pumps and turbines

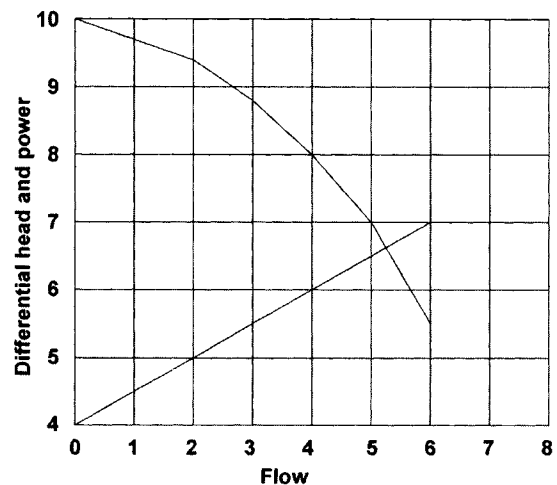


Figure 16.47 Typical centrifugal pump characteristics

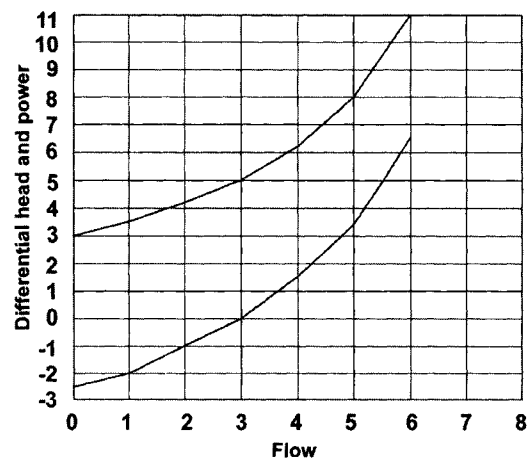


Figure 16.48 Typical inward flow radial turbine

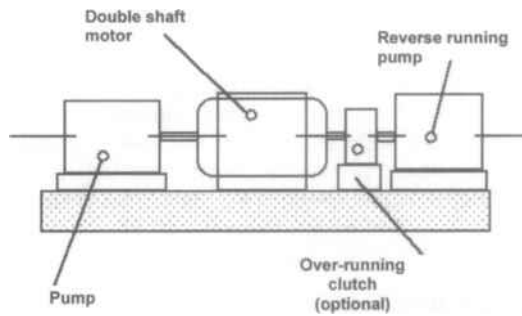


Figure 16.49 Typical arrangement of energy recovery turbine with a motor as the main driver

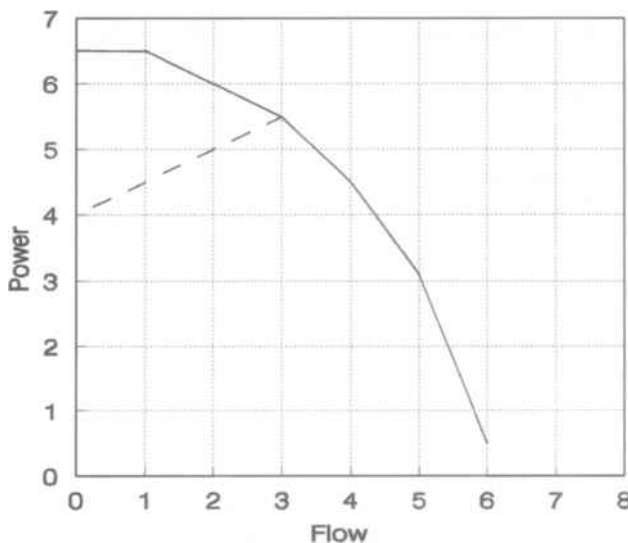


Figure 16.50 The effect of coupling an energy recovery turbine

Effects of power recovery

Figure 16.50 shows the effect of coupling an energy recovery turbine in-train with the pressurising pump as shown above. This shows the nett power delivered by the motor. It is calculated by subtracting the power recovered in the second chart from that absorbed in the first chart.

This nett power curve should be compared with the unassisted power curve shown in Figure 16.47. Note that at low flow, the motor is actually overcoming the power absorbed by both the turbine and the pump. As flow increases, the turbine begins to contribute and reduces the motor power requirements.

One way of reducing the low flow power demand is to install an overrunning clutch between the turbine and the motor. In this way the turbine is uncoupled from the train during starting at flows where it is absorbing power. It only becomes connected when power is being contributed.

16.17 Common errors which create pump operating problems

Most pump users and system designers do not think about pumps eight hours a day, every day; they think about pumps occasionally. Important factors revealed on the last project may not be remembered on the current one. Staff who gained good experience on the last project may have been transferred to a different department. The current project team may not have worked together before and an individual's depth of experience may be an unknown quantity. Most engineers rely on a web of personal contacts for support in "grey" areas; younger engineers may not have this backup support. The project manager must assess the qualities of all the project team and assign tasks accordingly.

Planning of pipework

In theory, starting a project from a clean sheet of paper, with an empty site, is the easiest type of project. But there does not appear to be a consistent logic applied to equipment arrangement and pipe runs. It seems obvious that the heaviest or biggest equipment must be located firstly where access is very good and adequate support is available. Heaviest/biggest equipment should be located around the periphery of the "plot" to provide the best access from outside. Heavy equipment should be located at ground level or as low as possible. Equipment which vibrates requires special consideration if the vibration is not to be transmitted through the supports. Many positive displacement pumps produce vibration and this factor must be considered when deciding locations and supports.

A number of pieces of equipment are not used in isolation but connected to other equipment. Pumps are connected into systems by pipework. Project planning should allocate priorities to pipework to allow "difficult" pipework to have good pipe runs while "easy" pipework can be fitted in the spaces left over. The choice of "difficult" and "easy" is not necessarily straightforward and requires some thought. The following points though should be considered:

- Size
- Pressure rating
- Differential temperature
- Water hammer effects
- Pressure pulsations
- Viscosity
- Essential routing requirements

Large pipes are obviously much more difficult to handle than small pipes. Access requirements around flanged connections may result in much wasted space. Pipe supports from the ground may be the only feasible solution. Space requirements for bends may preclude changes in direction and a straight pipe between A and B may be the only feasible option. Large pipes tend to be low pressure, although not always; and it may be worthwhile calculating the pressure times bore area; this can be used as a quantitative measure for priority. Higher pressure ratings require thicker pipe walls to reduce stressing to acceptable levels. Thicker pipe walls increase the difficulty of bending the pipe and increase the size of welds. The weight of pipe per unit length divided by the nominal diameter can be used as a priority factor. Piping which operates hot or cold, say 50 °C or more above or below the ambient temperature, may require extra space to include axial flexibility to cope with thermal expansion/contraction. The differential temperature divided by 50 can be used as a priority assessment. The fluid flowing through pipes possesses dynamic properties — kinetic energy. Pipework systems cannot always be steady-state. A piping system must start up and sometimes it must stop; emergency stop-pages, due to process upsets may be the worst case.

Water hammer effects should be evaluated. The liquid density is also an important factor. Water will produce much larger pressure changes than air for the same dynamic conditions. The water hammer effect can be judged by multiplying the pressure change by the pipe bore area. Pipework with large water hammer effects should be given a higher priority than lower ones. If these effects are likely to happen often, more than 7000 times over the whole life of the system, the pressure effects on fatigue should be investigated. Some equipment connected to pipework may not have a steady flow characteristic.

Some positive displacement pumps have significant cyclic flow variations which produce pressure pulsations. The flow variations produced by reciprocating pumps are well documented although the values given are usually wrong. Reciprocating

pump flow variations are a variable not a fixed value. Peristaltic pumps produce very noticeable flow variations. Lobe pumps and circumferential piston pumps can have cyclic flow variations which are large enough to produce troublesome piping vibrations. The system designer or piping designer must select a value of acceptable pressure pulsations which is appropriate for the pipework construction and supports and for all the equipment connected to the pipework.

Delicate instrumentation, such as flow meters, may require lower pulsation levels than those dictated by pipework mechanics. Pipework subject to pressure pulsations should be given a higher priority than pipework with steady-flow conditions. An early routing schedule should allow a better chance of providing a straight pipe, which will not vibrate, rather than having a number of bends to avoid existing equipment. Systems for high viscosity liquids should be allocated a higher priority than water-like liquids. The choices for suction pipe route options may be extremely limited when the liquid has flowing difficulties. Short, straight pipes with good fall are essential.

Pipework routing can be very important. Suction pipework which is not self-venting can pose tremendous installation problems if vent lines must be run considerable distances for safe disposal. Pipe falls are very important. Short pipes are better than long pipes. Straight pipes are much better than pipes with bends. Suction pipework is eliminated when submersible pumps are used. Cavitation is the most frequent pump problem. Using a submersible pump should help to eliminate a lot of the possible causes of cavitation. Liquid systems should be given priority over gas systems; compressors do not cavitate.

Logical project planning does not seem to work very well. Pipework for high risk applications and high pressure, viscous liquids with pressure pulsations, seem to be always fitted as an afterthought. The system components are far apart and the pipe runs are never straight. Pipe supports are poor and pipe anchors are frequently non-existent. It appears that no sensible criteria are applied to prioritise equipment positioning and pipe run locations.

Liquid properties

The proper selection of the best pump type is based on a good description of the operating conditions and the liquid properties. Pump specifiers and users have a habit of concentrating on "maximums" and forgetting about the "minimums". All operating conditions are important. The range of operating conditions is very important when evaluating pump performance. The pump manufacturer does not provide guarantees for undocumented conditions.

The NPSHa/NPIPa available is very important. Cavitation is a very serious problem and increasing NPSHa or NPIPa is not usually easy. Reducing the pump NPSHr/NPIPr usually means operating at lower speed and flow. The vapour pressure of the liquid is a critical factor in the NPSHa/NPIPa calculation. The vapour pressure of a trace element may be significant. Small quantities of water in high temperature processes can produce a very large volume of steam relative to the liquid volume of the other components. Centrifugal pumps may lose prime with a 15% gas volume. Reciprocating pumps may suffer major component failures with a 5% gas volume. The vapour pressure of the liquid may not be important if dissolved gas evolves from solution. The apparent vapour pressure, the pressure at which gas bubbles appear, may be considerably higher than the liquid vapour pressure. Entrained gas creates cavitation-like symptoms; early component failures can be expected.

Very small quantities of solids can increase component wear dramatically. Materials of construction are adjusted when solids are included in the duty specification. The pump operating speed may be reduced to compensate for wear rates. It may not be possible to successfully adapt an installed pump to cope

with solids. Reduced flow and high spares usage are the usual effects of handling unspecified solids.

The pump manufacturer assumes all changes in operating conditions are slow unless specifically identified as rapid. Temperature changes are slow enough not to create thermal shock. Pressure and flow changes are also slow enough not to create surge problems. Rapid changes in conditions are very likely to cause early failure of major components. The cost of spares and lost production will be high.

Equipment positioning

The early planning of systems must include the relative positioning of the system components. The importance of good positioning increases as the "liquid" becomes more difficult to handle. In some processes "liquid" is a poor description of the process medium. Viscosity can be so high that the process medium will not flow under the influence of gravity; positive assistance is necessary for flow to occur. When the process medium has very high viscosity it is sensible to arrange the medium to fall into the pump. Trying to lift the medium into the pump is not a good idea. System planning should organise the suction source to be above the pump suction connection. This approach is always a good idea even with water-like liquids. The suction source should be as close as possible to the pump to reduce piping losses. Difficult liquid applications should have the equipment locations allocated very early in the project calendar and before easy systems such as water and gases.

Many systems rely on atmospheric pressure to provide the pump suction pressure. Atmospheric pressure is not constant and varies with the weather conditions. The standard barometric pressure, at sea level, is 101.325 kPa. Weather conditions cause a variation of about $\pm 3\%$. Most importantly, many installations are not at sea level. At 500 m the standard air pressure has dropped to 95.461 kPa and at 1000 m to 89.876 kPa. From a water pumping perspective the effective suction lift of a pump is reduced by about 0.5 m for every 500 m of altitude. Also of interest is the variation in "g". At sea level the standard value is 9.80665 m/s². At 500 and 1000 m the standard values are 9.8051 and 9.8036 m/s². In pumping the only constant which can be relied upon is π .

Pipework design

Pipework design is very difficult. This is why many installations are poorly designed and suffer reliability problems and fatigue failures. Most piping appears to be designed by software which only considers "Code compliance", that is stressing which guarantees insurance cover. The prime function of the pipe, to carry fluid, does not seem to be considered; hydraulic considerations are usually ignored. In many cases the final pipework design is safe but completely unsuitable for the purpose.

Hydraulically, the best pipework is straight. Bent pipes are better than pipes fabricated with pressed bends. Pipework which is likely to be subjected to continuous pressure pulsations requires special attention. Pressure pulsations cannot create pipe vibration if the pipe is straight. Pressure pulsations act on bends to create the vibration. Sharp bends, pressed bends, create more vibration than gentle bends and bent pipe. Experience has shown that 45° sets, used in pairs, perform much better than bends.

Pipework which is likely to be subject to continuous pressure pulsations requires very good support and restraint. Pipework suspended by hangers will generally vibrate unacceptably and the vibration may induce unacceptable stressing. This pipework must be supported by clamps incorporating damped restraints and with rigid anchors at strategic locations. It may induce structural vibration if clamped rigidly, at high elevations, to building steelwork. The best results are obtained with low level pipework supported directly from concrete.

Successful pipework design can only be accomplished when the designer considers the actual hydraulic process which is taking place inside the pipe. The design must be appropriate for the hydraulic conditions. All pipework is not equal.

16.18 Positive displacement pumps — load-unload control systems

Introduction

There are several applications where load-unload control has proved to be the best practical solution. Steelworks hydraulic power supply and steelworks descaling are two typical applications which only differ in the process liquid. Very large high pressure systems have used multi-stage centrifugal pumps with load-unload control and these pumps suffer similar problems (broken shafts) when the control system deteriorates or is inappropriate.

Steelworks use hydraulic power to actuate and drive much equipment. Equipment located close to hot metal poses a fire risk if hydraulic oil leaks and is ignited. For this reason many hydraulic systems have utilised water or water-oil emulsions. The lubrication qualities of water can be significantly improved if 5% or 3% soluble oil is included without resulting in a flammable liquid. Descaling utilises cold water to produce thermal shock which violently fractures and loosens the scale on hot metal surfaces. Centralised hydraulic systems and centralised descaling systems operate at pressures of 100 barg up to about 450 barg. Plunger pumps are used when flows up to approximately 120 m³/h from each pump, are required. Small systems would use three pumps, two operating and one standby. Large systems may use five to ten operating pumps with two standby units.

Typical system

Water, or water/oil emulsion, is stored in a header tank at an elevation to provide sufficient NPIP_a for the pumps. Water/oil emulsion must be continuously recirculated around the tank to prevent separation and also to allow oil concentration monitoring so the oil content can be adjusted if required. The feed from the header tank flows via a pair of strainers, one working/one standby, to the suctions of the three pumps. Each pump has a flow-through suction pulsation damper and a discharge pulsation damper. The flow-through style of damper is preferred for multi-pump installations because the degree of uncoupling between the pump and the system is much higher than appendage styles. There is much less chance of pump interaction affecting the system performance. The pump relief valve is located immediately after the discharge damper. The load-unload bypass valve is mounted before the non-return valve and the isolating valve. The one or two operating pumps feed a bank of accumulators which are used to store high pressure water. The use of accumulators allows the system to supply instantaneous flow rates much greater than the nominal pump capacity. As hydraulic power and descaling requirements are intermittent, the accumulators and the pumps can supply the peak demands. The pumps can recharge the accumulators when demand is low.

Electric motors

Load-unload control is better than on-off control because the electric system, starter and motor, are not subjected to the effects of high inrush currents. Motor starting, especially when hot, may be severely restricted for motors over 45 kW. During bypass operation the motor and the pump absorb very little power. Power consumption can be reduced even further if a modern soft starter is used. Modern soft starters often include a low power and/or low speed unload control. The motor is able to operate efficiently at low load and possibly at reduced speed. Load-unload control can be applied very rapidly without overheating the motor or wearing out the contactor. Load-unload is

not instantaneous but requires a finite time to change from low-pressure bypass to high-pressure on-load. Sizing of the accumulators is critical for the load cycle to operate smoothly.

Operation

These types of intermittent system are controlled by pressure. As the system flow demand reduces, the pump over-capacity is absorbed by the accumulators; this causes an increase in system pressure. When the pressure reaches a predetermined value, say 85% of maximum, one pump is unloaded. If the pressure continues to rise the second pump will unload at 100% pressure. At this condition the maximum volume of water is stored in the accumulators and the total pump flow is zero. If the system pressure remained constant at 85% then the system demand would be equal to the flow from one pump. If the system pressure decayed, because the demand was greater than a single pump flow, the unloaded pump would be loaded to prevent the system pressure reducing below a preset minimum.

This mode of operation describes the traditional control system which used fixed pressure set-points, pressure switches, to initiate control sequences. Systems using a PLC and pressure transducers, would consider the static pressure and the rate of pressure change to decide on load-unload set-points. The set-points would be variable rather than fixed.

Bypass valves

Load-unload systems suffer two recurring problems. Both multi-stage centrifugal pump installations and plunger pump installations suffer when an inappropriate bypass valve is used. Plunger pump installations frequently experience pipework vibration problems. The bypass valve is nominally an open or closed valve. In practice the valve must be slow-acting and have good throttling capabilities. Many installations are built with power actuated open/close valves, powered isolating valves, and the cycle time is preset. Because of the poor part-open flow characteristics of isolating valves the high pressure system is subject to surge and pressure pulsation problems.

In extreme cases pump components such as centrifugal pump shafts, crankshafts and plunger pump crossheads, fail due to fatigue induced by the shock loadings. Hydraulically actuated valves, using the process water for actuation, have generally been unsuccessful because of the poor lubricating qualities of the water. The bypass valve should be a pressure control valve, see Figure 16.51, which has specific throttling characteristics.

The globe valve shown has a contoured plug which provides a guaranteed throttling characteristic. The pressure rise during

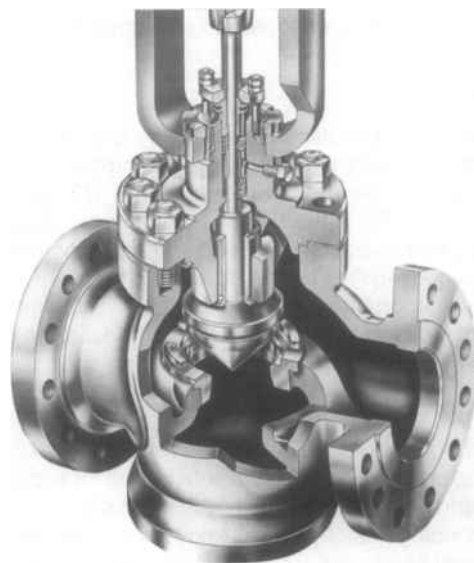


Figure 16.51 Typical high pressure control valve

valve closure can be smooth and progressive and eliminate all surge effects. This style of control valve would normally be pneumatically operated but could be electrically operated. If a PLC was used for system control the bypass valve could be modulated to provide 0 to 100% pump flow for low flow situations. Pipework vibration can be experienced by centrifugal pump and plunger pump installations which try to use inappropriate bypass valves.

The flow surge created by an "isolating" valve opening or closing produces an associated pressure pulse. The pressure pulse causes pipework vibration. The pipework vibration is usually of very short duration but can be violent. Pipework failure through fatigue is possible. Short duration vibration can also be triggered by the equipment using the high pressure water or water/oil emulsion. If the equipment isolating valve is not slow-acting or does not have a good throttling characteristic then surge associated failures are likely.

Damping

Plunger pump installations frequently experience continuous high levels of pipework vibration. Pipework routings are usually far from ideal and elevated pipework may be suspended from building structural steelwork rather than the preferred low-level pipework firmly attached to the ground. The high vibration levels are due to a mismatch between the pump damper specification and the pipework construction style. The pump manufacturer is not usually involved in pipework design. If the system designer does not specify an appropriate level of damping for the distribution system the pump manufacturer will only provide a damper based on the pipework design local to the pump. The system designer is responsible for the correct operation of the whole system. Pump residual pressure pulsations are easily transmitted through the whole system and can create vibration anywhere. Co-ordination and communication are the keys to success.

16.19 Plunger pumps for supercritical extraction service

Introduction

It is claimed that by using carbon dioxide supercritical technology, purer and therefore more valuable end products may be produced. Optimal process results relative to product quality depend upon the ability to control the process parameters in the high pressure loop. As control of the carbon dioxide process parameters requires sophisticated techniques and knowledge, so does the design of reciprocating pumping equipment to be used in these processes. The combination of these conditions give rise to the desired operating characteristics now described.

Background

Carbon dioxide supercritical extraction is a far reaching separation-oriented process that is growing in commercial application. Early commercial plants were designed in 1973 and went into service in 1979. Since then many additional and larger plants have come into operation. The efficient application of this process technique requires highly reliable and functional capability of the more important system components. Thus the pumping equipment required to pressurize the carbon dioxide liquid is a key process component.

Applications

Food and pharmaceutical industries require the extraction of basic, rare, aromatic and/or taste substances for economic productivity and high product quality. Although supercritical separation technology has been well known for many years, it has only recently been used for industrial scale manufacturing applications. The prime application is in the extraction of substances from plant life raw materials.

The prime benefits of the supercritical extraction process relate to the non-destructive handling of the raw material and in addition the desired end product has an extremely high degree of purity. Also, the process can be made extremely selective as to the material(s) extracted. In fact, by using selected combinations of pressure and temperature, several different materials may be extracted from a common raw material.

The process

As can be imagined, the amount of the supercritical liquid throughput must be exactly maintained, controlled, and monitored. Pressurization of the solvent stream is usually accomplished via a positive displacement plunger type pump, designed to accommodate the extraction medium's physical properties. Plunger pumps are especially adaptable to this application in view of their high discharge pressures and small throughput capacities. As an example, because of the compressibility of liquid CO_2 , an especially critical necessity is the reduction of the pump's internal clearance volume to achieve optimum volumetric efficiency.

Experience shows that plunger pumps deliver an excellent overall efficiency and thus are highly economical machines to develop the required pressures and capacities. This result is in part attributable to the proportionality of pump speed vs. capacity and its relative indifference to differential pressure. Performance is as illustrated in Figure 16.52.

A high pressure supercritical recycle process

Figure 16.53 depicts the temperature/entropy curve for a carbon dioxide loop for a typical extraction process. A pump pressurizes the carbon dioxide liquid from I to II (suction pressure P_1 to discharge pressure P_2). At pressure P_2 , the carbon diox-

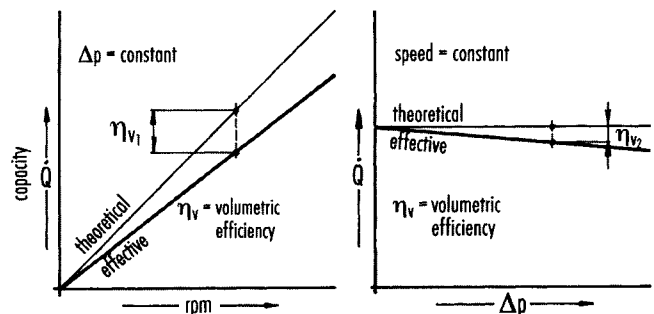


Figure 16.52 Dependency of volumetric flow and discharge pressure of reciprocating plunger pumps
Courtesy of Uraca Pumpenfabrik GmbH & Co KG

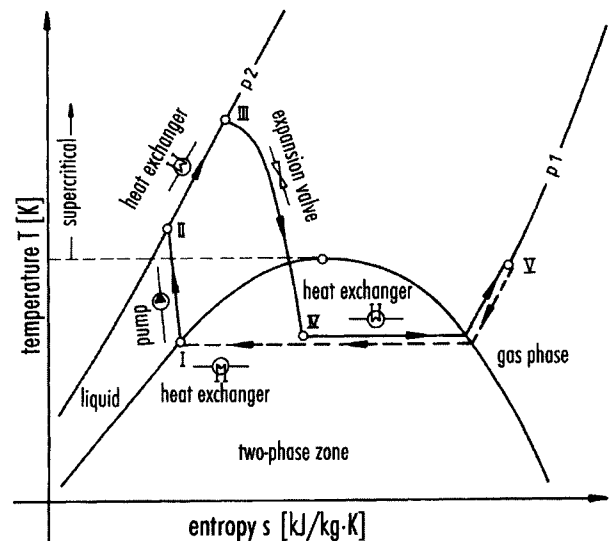


Figure 16.53 Temperature-entropy diagram (CO_2 extraction process)
Courtesy of Uraca Pumpenfabrik GmbH & Co KG

ide is heated in a heat exchanger from II to III i.e. the process temperature. An extractor is employed to achieve the desired carbon dioxide combination of pressure and temperature and is let down from III to IV. An evaporator is used to proceed from IV to V at which point the heavier product is separated out. The "purified" carbon dioxide proceeds from V to I and is condensed, sub-cooled and at process point I, sent on at P1 to the pump suction.

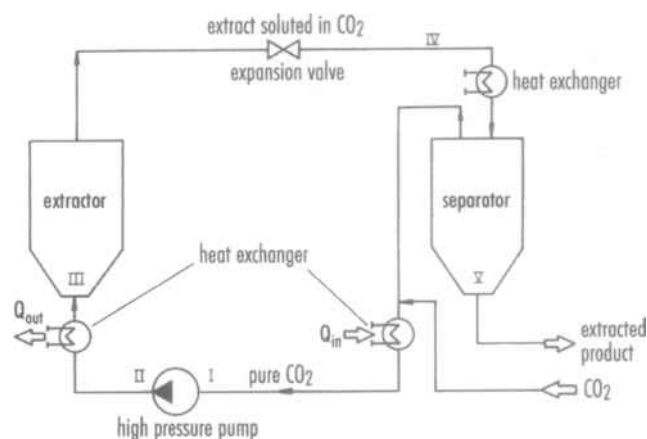
Potential variations in the pressure, temperature and flow process conditions permit the extraction of diversified substances from various raw materials. Therefore, the process is extremely flexible and lends itself to many potential applications.

Supercritical extraction system

Assuming a common raw material, it is also possible to extract selectively several different components (mostly as liquid) as previously indicated. In general, a supercritical extraction system consists of four major components:

- A pump to pressurize the extraction medium
- A pressure vessel (extractor) where the extraction process takes place
- A pressure vessel (separator) where the extract and medium are separated
- Heat exchangers to control the extraction and separation temperatures

Figure 16.54 shows a typical process arrangement for these elements. The Roman numerals correspond to the entropy diagram in Figure 16.53.

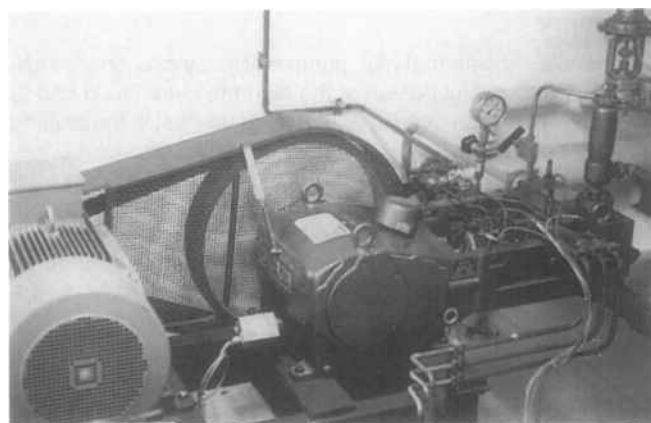


Liquid carbon dioxide pump requirements

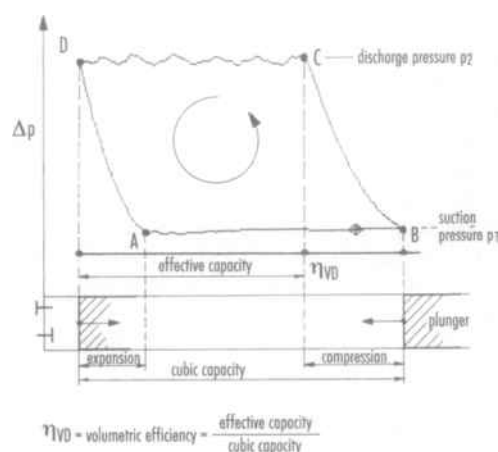
There are specific requirements for the design of a high pressure pump for use on liquid carbon dioxide. Initially, the pump must be capable of pressurizing the liquid to pressures over the supercritical threshold. Liquid carbon dioxide is extremely compressible as may be seen from the thermodynamic table. There is also the problem that the temperature gain during the pressurizing process is not precisely controllable. As such, especially in large pump applications, there is the question of not being able to accurately predict pump capacity. This problem must be solved through experience and empirical measurement. To understand these pump issues further, a research project was undertaken to explore what happened in the pressurizing chamber of a plunger pump so that this data could be used to further advance the design technology.

The pump was fitted with instrumentation to measure the following: pressure in the space between the suction and discharge valves, inlet and outlet temperatures, cooling medium temperatures and ambient temperature. See Figure 16.55.

Figure 16.56 shows the developed indicator diagram through the synchronization of the functions in the liquid cavity and



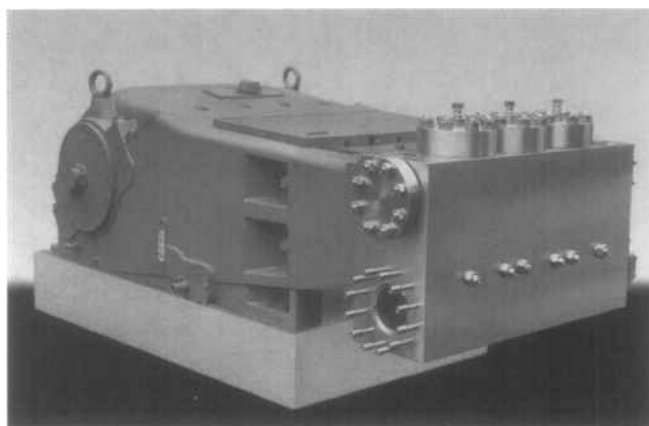
plunger stroke. In this diagram, A to B is the suction stroke. B to



C is the pressurization to the required discharge pressure; and C to D is the discharge valve opening permitting the liquid carbon dioxide to enter the discharge line.

The relationship of C to D and B to D demonstrates a volumetric efficiency η_{VD} , considerably less than that obtained when using water. This is explained by compressibility. D to A shows the expansion of the liquid carbon dioxide remaining in the pump's clearance volume. The cycle is repeated starting at A.

Repetitive testing under varying process parameters provided extremely useful empirical data to enable the pump equipment design to supply exactly the required process service conditions. In addition to concerns about the strength of materials, cavitation-free operation is an absolute necessity to maintain trouble-free operation. Also, to maintain a high degree of operational efficiency, the seals on the suction and discharge valves are an important consideration.



Summary

Test results indicate that high pump efficiency may only be obtained by the careful design of the high pressure liquid end to absolutely minimize dead space. Also of interest is the stuffing box sealing system, in the light of liquid carbon dioxide lubrication and cooling characteristics. A method of monitoring the functioning of the seal system is a prime design consideration. In summary, pumping liquids used in supercritical applications requires especially suitable construction materials and pump design technology (See Figure 16.57) based upon practical application and creative research and development.

Application courtesy of Uraca GmbH + Co KG

16.20 Sealing systems for thermal oil pumps

Introduction

In industrial heating, thermal oil has become a popular heat transfer medium. Compared to hot water systems thermal oil can transfer higher temperatures at lower pressures. This means that hot oil systems allow a lower pressure rating. An electrical heater or burner heats up the oil, users consume the heat, and there is a circulation pump. The trouble-free operation depends primarily on a reliable circulation pump with a corresponding shaft sealing system. Every user of hot oil systems should be aware of the different sealing systems and pump concepts and their advantages. Using the cheapest pump solution often leads to high maintenance costs during operation.

Pump concepts

Low-cost centrifugal pump concepts normally use standard single-stage, end suction foot-mounted ductile iron volute casings with a standard single mechanical seal that is separated from the hydraulic parts by an air-cooled intermediate spacer. The temperature limit is typically 350°C. However, in applications above 320°C this standard foot-mounted casing can be overstressed and distorted by typically unknown forces and moments generated by the piping system during heating of the plant. For temperatures above 320°C, up to 400°C, a pumping concept based on the standard chemical pump design is often a better solution. The pump casings can be equipped with centre line mounting, see Figure 16.58. The material can be improved to cast steel and different sealing systems can be used. When cast steel is used, it is also possible to use welded drain connections, which are much easier to seal than screwed connections. These are becoming more common in new installations, see Figure 16.59.

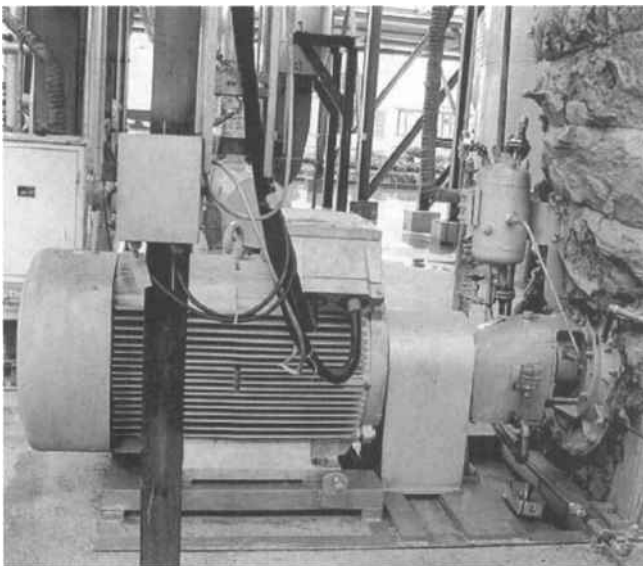


Figure 16.58 Typical centreline mounted pump installation
Courtesy of Dickow Pumpen KG

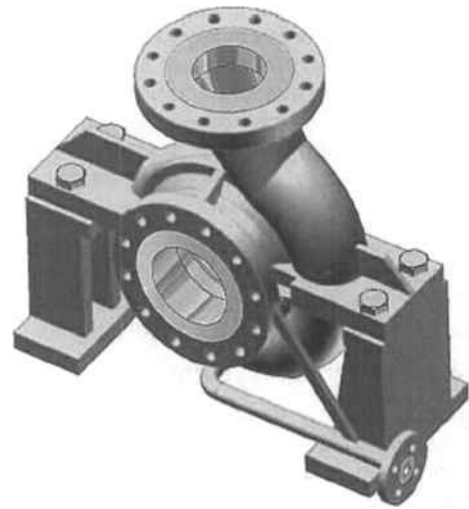


Figure 16.59 Example of a volute casing with a centreline support
Courtesy of Dickow Pumpen KG

Sealing systems

Especially for low viscosity and high temperature synthetic oils; e.g. Dowtherm or Diphyl; sophisticated tandem seal arrangements or magnetic couplings are required. In Figure 16.60, an ideal tandem seal arrangement is shown. In order to minimise the influence of solids, such as decomposition sludge on the seal lifetime, the seal face combination is SiC against SiC (silicon carbide is a very hard ceramic material); the bellows are rotating in order to prevent clogging and the seal chamber is designed as large as possible to prevent the accumulation of solids and gases/vapours. The two seals, on both the product and atmospheric sides, are lubricated by an atmospheric air-cooled thermosiphon vessel which also prevents damage to the seals, even during dry running conditions.

A constant lubrication and cooling circulation flow (of buffer fluid, e.g. oil) is generated by a pump ring. Failure of the product seal can be detected by a level switch in the vessel and the at-

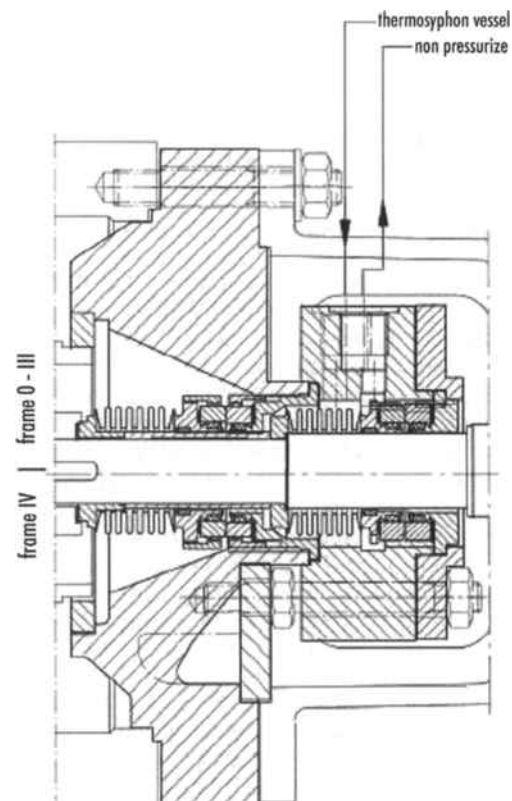


Figure 16.60 Tandem bellows seal arrangement in a tapered seal chamber
Courtesy of Dickow Pumpen KG

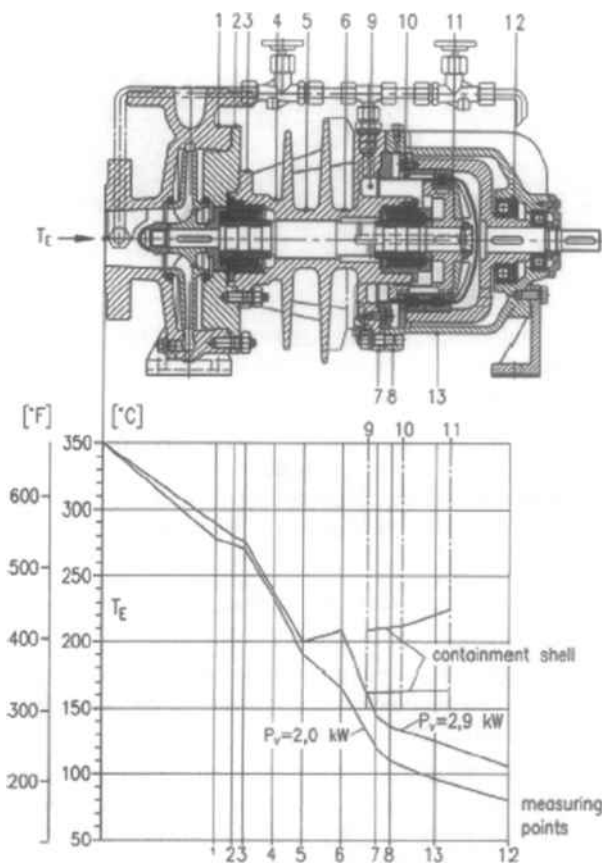


Figure 16.61 Air-cooled magnetic drive pump showing temperature profile
Courtesy of Dickow Pumpen KG

mospheric seal will prevent leakage. For applications above 350°C, it is possible to have additional water cooling with a cooling coil inside the thermosiphon vessel.

Another reliable solution is static shaft sealing by magnetic coupling, which is also air-cooled and is absolutely leak-free, Figure 16.61. The operating principle of the magnetic coupling is very easy. There are internal and external rotating magnets that are separated by a stationary containment shell. This special pump design separates the magnets with an air-cooled finned section from the hot pump casing, which means that the magnets are running at a reduced temperature level, maximum 250°C. The magnets are also additionally protected against solids because they are separated from the main process flow.

Once again SiC against SiC is used for the liquid-lubricated bearings in order to minimize wear. The standard containment shell material is Hastelloy C. Eddy current losses are generated through the rotating magnetic field and these heat up the shell.

If the losses are more than 2 kW, the heat radiation of the casing will be too small and must be supported by an additional air-cooling loop. The standard design can even be improved with a close-coupled motor and a ceramic shell, Figure 16.62. The flanged motor prevents misalignment of the flexible coupling and the ceramic material has zero magnetic losses because it is an electrical isolator and non-magnetic. Secondary containment with a leakage monitoring device can be added for additional safety.

Field experience and application

In 2002 a leading Swiss heat transfer systems company awarded contracts for several heat transfer systems with multiple heaters for polyester plants in China. The heaters had a capacity of 14 to 16 MW. The selected heat transfer medium was synthetic Dowtherm A. Every heater generated about 157,600 kg/h vapour with a temperature of 337°C and a pressure of 3.5 bar. Process heating using thermal fluids in the vapour phase (flash system or secondary vaporiser) makes it possible to distribute a constant supply of heat uniformly to several users. The capacities range from 100 kW up to about 45 MW per heater, thus covering a broad spectrum of heating requirements. Even larger capacities can be achieved by combining several units in a battery, which also increases plant availability at the same time.

The circulation pumps of such a system are exposed to extraordinary conditions. At a temperature of 330°C, a flow of 530 to 630 m³/h against a head of 90 m must be circulated. The typical low-cost pump with a standard foot-mounted casing and a single mechanical seal, as described earlier, proved to be too weak for this kind of application. The low viscosity synthetic oil can additionally lead to leakage through the single mechanical seal. Therefore heavy duty hot oil pumps, were selected. A robust design with centre line-mounted cast steel casings and a tandem seal arrangement were selected as the sealing system, see also Figures 16.59 and 16.60. The first pumps installed have been running for several years without any major problems

Pump selection

How can you select the right pump and sealing system? Unfortunately, there are no fixed temperature limits, it also depends on the piping and pump size, etc. In the region above 320°C and when using synthetic oils, it is strongly recommended to carefully examine the pump and seal design. When comparing double seal systems and magnetic couplings, the latter is not always more expensive. In regions up to 55 kW the initial costs of magnetic coupled pumps are even lower. For larger motors however (and therefore larger couplings), the double seal systems look more attractive. The longest MTBF (mean time be-

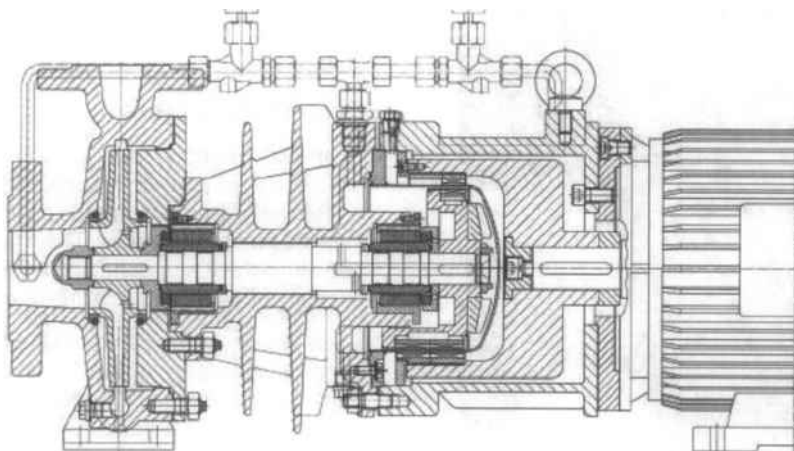


Figure 16.62 Air-cooled magnetic drive pump with ceramic containment shell
Courtesy of Dickow Pumpen KG

tween failure), up to ten years, can only be reached with an appropriate magnetic coupled pump.

Application courtesy of Dickow Pumpen KG

16.21 Progressive cavity pump stator technology for improved candy production

Introduction

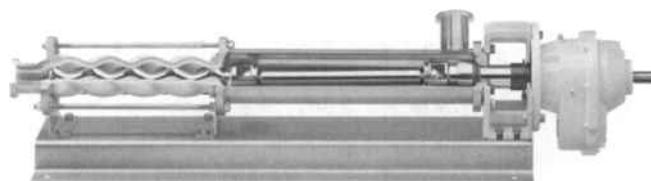
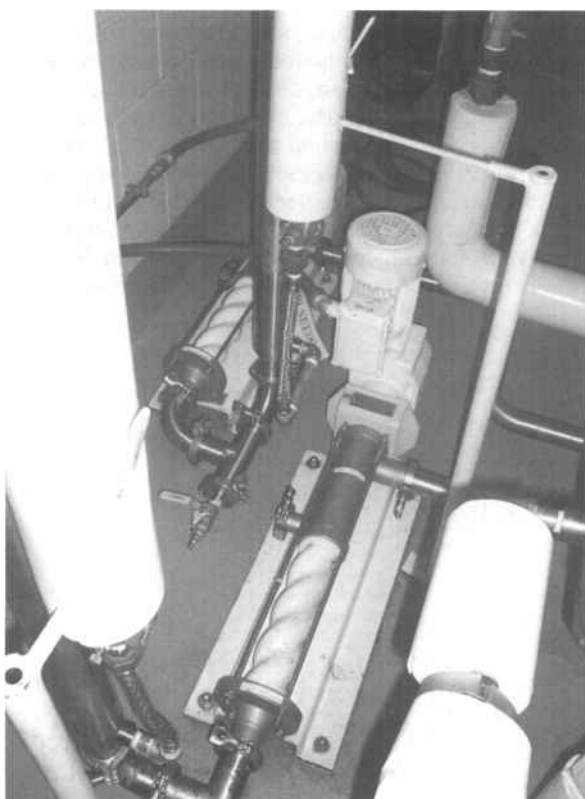
One of the oldest continuously operating candy companies in the USA undertook an expansion programme involving a new, state-of-the-art facility which included a brand new moulding line for candy bar production. Before the move, the company had been relying on traditional positive displacement (PD) pumps to transfer the candy bar fillings from storage to the filling line. But, even as the company began planning the expansion, design engineers were encouraging management to consider progressive cavity, (PC) pumps, for the new facility, see Figure 16.63. It was suggested that, among other benefits, PC pumps would run at the higher pressures needed for the viscous candy fillings.

The progressive cavity pump

In operation, a progressive cavity pump's single helix rotor rotates within an elastomeric double helix stator to form sealed cavities that progress from the suction side to the discharge end of the pump. The continuous seal between the rotor and the stator helices moves the product steadily, without valves or pulsations, at a fixed flow rate proportional to the rotational speed of the pump and independent of pressure fluctuations that can result from varying densities and viscosities of conveyed product. See Figure 16.64.

Several factors make these sanitary progressive cavity pumps the right choice for the new facility:

- The pumps use an Even Wall® stator, meaning the same performance can be achieved with a compact 2-stage pump that would usually require a much longer 4-stage with conventional stator geometry.



- The stators are also moulded to size, not cut, with integral seals molded into the ends, and are offered in a wide selection of food-grade elastomers.
- These more economical and longer lasting, closed joint sanitary pumps are perfectly suited for candy fillings, whereas a dairy-compliant open joint would be unnecessarily maintenance intensive and expensive for this application.
- Their 'block,' or close-coupled, design conserves additional space.
- The units pump without pulsation; and at variable speeds they can be counted on to pump the fillings gently, with no shear or product damage.

Four sanitary PC pumps were purchased. They had Therban® even wall stators, Duktal®-coated stainless steel rotors, and closed sanitary joints. The closed joint pumps are furnished with cost-effective pin joints and filled with special food-grade grease, making these pumps especially suited to high operating pressures. The pumps are rated to handle up to 0.25-US gpm on continuous service, customised for viscosity of 125,000 cP, at 120 °F, at pressures up to 24 bar.

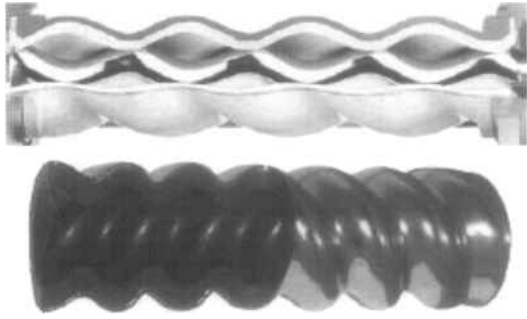
The pumps are equipped with variable frequency drives for process control, with speeds proportional to a 4-20 mA signal coming from a level sensor on the filling machine. The space-saving block (close-coupled) design utilizes the gear reducer bearings to absorb the axial and radial loads of the pump. In fact, these units are assured of being capable of a minimum of an AFBM (Anti-Friction Bearing Manufacturers Association) L-10 life of 50,000 hours. Optionally, an L-10 life of >100,000 hours is also available.

The block pumps require only simple bent steel 'top hat' base plates for mounting. Therban® is a proprietary hydrogenated nitrile butadiene rubber (HNBR) elastomer. The compound is made to CFR 177.2600 and is considered "food grade". HNBR offers superior abrasion and temperature resistance compared with NBR compounds or ethylene propylene diene monomers (EPDM) which are commonly offered for food applications. The HNBR in an Even Wall® configuration has consistently outlasted NBR by a factor of five times or more in Even Wall® stators.

Even Wall® stators

Even Wall® stators, see Figure 16.65, are made with a special procedure using a metal tube that is hydraulically bent into a double helix, the same shape as the helix forming the cavity inside the pumping element. This makes the thickness of the rubber within the stator constant, as opposed to the thin and thick sections of elastomer existing in a normal cylindrical tube.

Even Wall® stators can handle twice the pressure of conventional designs on non-abrasive fluids, with an even smaller footprint than conventional PC pumps. Both hysteresis failures and bond failures are practically eliminated. These stators are excellent for food applications that have wide temperature variations that can result from low temperature operation and high temperature cleaning. Users report that these stators routinely



last up to five times longer than conventionally designed stators in these applications.

Duktil® is also a proprietary coating. Sometimes referred to as “chromium nitriding”, it involves plating chromium at extremely high currents and heat. The result is a coating that exceeds a hardness of 90 Rc and actually diffuses into the base metal. Consequently, it can bend (having ductile properties) without cracking, as standard hard chrome can.

Summary

The progressive cavity pumps currently transfer nougat, toffee, fudge and caramel fillings. The company has achieved savings by the minimal downtime required for repairs and in low energy usage. Additionally, the same pumps can be used for the four different fillings, with their viscosity variations, because of the variable speed possibilities and the ease of cleaning between operations.

Application courtesy of seepex GmbH & Co KG and Kächele GmbH

16.22 Digital controllers for diaphragm dosing pumps with speed-controlled drive motors

Introduction

There are a wide range of highly sophisticated dosing tasks in water technology and process engineering which place high demands on dosing pumps in terms of precision, reliability and, in particular, monitoring the dosing process. Examples of these complex applications include dosing anti-scalants and anti-fouling agents in reverse osmosis processes and in the growth sector of diaphragm filtration. Further critical examples include dosing various biocides and defoaming agents in paper production and dosing cleaning agents and disinfectants in the case of CIP applications for the food and beverages industry.

Reliable dosing of concentrated acids and alkalis has proved to be a difficult task in the detoxification and neutralisation processes of industrial process and waste water treatment. Industry continues to use conventional systems for dosing and process monitoring despite the high demands placed on them. The newly developed digital flow monitors can now help give the user precise control of dosing behaviour. The diagnosis system detects errors in the dosing head and reports malfunctions reliably and without delay even at the lowest dosing rate settings in the ml/h range. (See Figure 16.66)

Reasons for dosing errors

Among the most common causes of faults when dosing with diaphragm pumps are:

- Air and/or gas bubbles in the dosing head
- Cavitation bubbles in the dosing head
- Leakage in the suction or discharge valve
- Inadmissibly high operating pressure or system pressure fluctuations

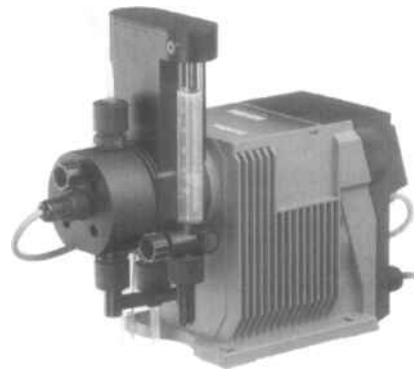


Figure 16.66 Dosing pump with priming chamber and flow monitor
Courtesy of Alldos Ltd

Conventional solutions for monitoring volumetric flow

Until recently the most commonly used solutions for dosing monitoring in the case of diaphragm dosing pumps have operated according to the “floater principle”. This method involves moving a float upwards in a pipe during the pressure stroke. The float falls again during the suction stroke of the pump. This movement of the float is recorded visually, magnetically or inductively.

Adjustment of the dosing rate of the pump is then achieved by moving a switch and/or adding a bypass. This is precisely where the weaknesses lie. These settings have to be adapted to the relevant operating conditions of the pump and when changing the stroke length and/or the stroke frequency. This method of dosing monitoring can often not be used in the case of large variations in stroke frequency or when dosing viscous liquids.

Operating principles of the flow monitor

The indicator diagram displays the pressure profile across the suction and pressure strokes of the piston or diaphragm. Figure 16.67 shows the pressure profile of a diaphragm pump which is functioning correctly. Starting at point 1, the pressure stroke features a compression phase with a build-up of pressure up to the opening pressure of the pressure valve at point 2 and this phase is followed by the feed process into the pressured line until outer dead centre (point 3) is reached. During the return stroke, there is a drop in pressure down to the suction pressure at point 4 with a subsequent suction process until the inner dead centre (point 1) is reached, i.e. the start of this cyclical process.

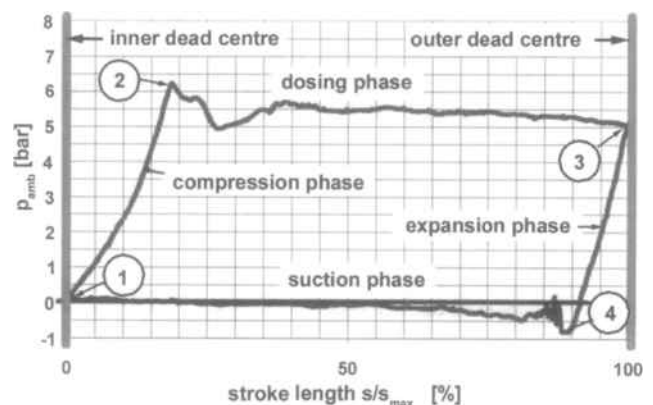


Figure 16.67 Indicator diagram for a dosing diaphragm pump which is functioning correctly
Courtesy of Alldos Ltd

Error detection

A properly functioning diaphragm pump is used as a reference and stored in the microprocessor. Even minor faults can be detected by means of changes in the current indicator diagram.

Figure 16.68 shows two frequently occurring faults in the dosing process through comparison with the error-free pressure profile (curve 1). Should there be air and/or gas bubbles in the dosing chamber (curve 2), pressure builds up more slowly due to the much greater elasticity. This means that it takes longer to reach the system pressure and that the dosing volume of each stroke is significantly smaller.

In the case of large errors on the suction side of the pump, extensive cavitation can occur as shown in Figure 16.68 (curve 3). The reasons for this can be too small flow cross-sections, too low suction in pressure or excessive levels of suction or excessive viscosity. Vapour pressure dominates the entire suction stroke and only dissipates late in the pressure stroke. This scenario also results in a smaller dosing volume per stroke due to the delay in reaching the system pressure.

Figure 16.69 shows two further frequently occurring faults in the dosing process through comparison with the error-free pressure profile (curve 1). If leakage occurs in the suction valve (curve 2), pressure builds up more slowly due to the leakage in the suction valve and the pressure falls before the outer dead centre is reached as soon as the leakage rate is larger than the current flow rate of the pump.

Should leakage occur in the discharge valve (curve 3 in Figure 16.69), a rise in pressure occurs before the end of the suction stroke when the leakage rate in the discharge valve is larger than the current suction flow of the pump. Moreover, the pres-

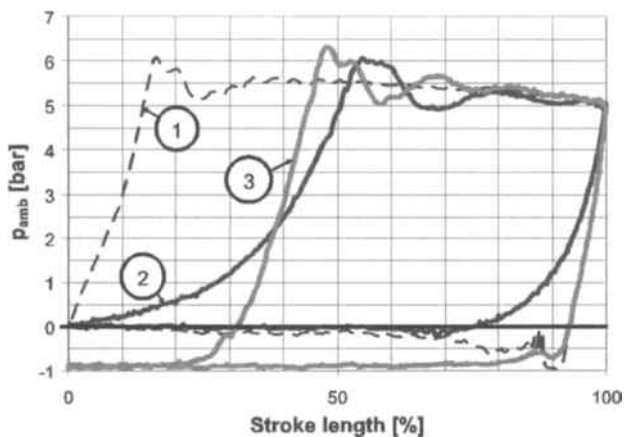


Figure 16.68 Indicator diagram when pump is functioning correctly (1), when there are air bubbles in the dosing chamber (2) and when cavitation occurs (3)
Courtesy of Alldos Ltd

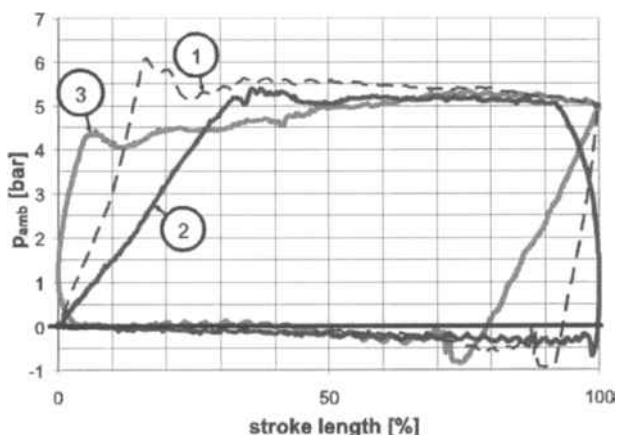


Figure 16.69 Indicator diagram when pump is functioning correctly (1), when there is leakage in the suction valve (2) and in the pressure valve (3)
Courtesy of Alldos Ltd

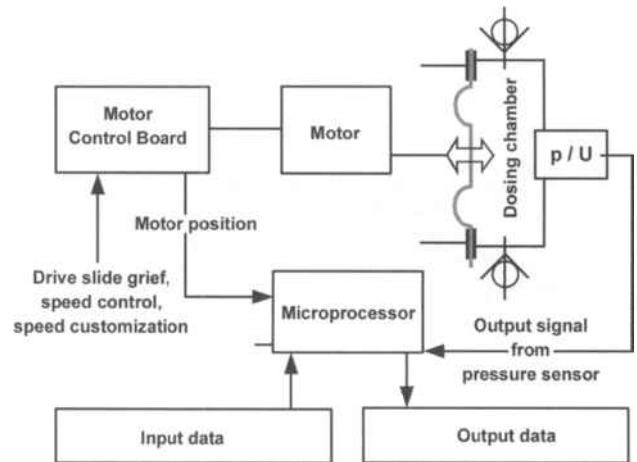


Figure 16.70 Schematic of system used to generate the indicator diagram
Courtesy of Alldos Ltd

sure falls more slowly at the start of the suction stroke as a result of post-flow in the discharge valve.

This indicator diagram is also suitable for detecting other faults; for example, if the set system pressure is exceeded. This can be identified and evaluated.

System solution

The dosing pump also incorporates a pressure sensor. This enables the existing microprocessor to be used for both motor control and processing the measurement values.

As can be seen from Figure 16.70, the microprocessor continuously records the pressure in the dosing chamber and, using the motor control, the motor position which can also be used to determine the diaphragm position on the basis of the drive kinematics. This means that the microprocessor can generate the indicator diagram on a continuous basis. Evaluation algorithms have been developed to enable detection and evaluation of the dosing errors.

By setting the basic monitoring parameters for volumetric flow to cover a wide range of standard applications, depending on the error in question, a fall in the dosing rate of only 30% can be detected.

It is also possible to use the indicator diagram's memory of representative points and use them for the purpose of diagnosing errors. See Figure 16.71.

The processor also takes an average of the values to continuously calculate the feed pressure in the dosing chamber. This value is representative of the current system pressure and can be queried at any time.



Figure 16.71 Display when pump is functioning correctly (upper). Display when there is a flow error (lower)
Courtesy of Alldos Ltd

Summary

Continuous monitoring of diaphragm dosing pumps by recording and automatically evaluating the current indicator diagrams opens up many opportunities for operational monitoring:

The current system pressure parameter enables a process to be established which is largely independent of the pump size.

The indicator diagram is largely independent of speed, viscosity and temperature. This establishes the same system for detecting errors across the pump's entire volumetric flow range without defining a working point.

Recording the current system pressure enables users to balance out pressure-dependent fluctuations in the flow rate of the pump by adapting the speed.

Application courtesy of Alldos Ltd

16.23 Positive displacement medium pressure pump system for tube press application

Introduction

The removal of waste iron ore from the furnace exhaust along with other waste products is an important stage in tube press processing of waste products at any steelworks. The ore is then re-processed into briquettes for re-cycling. The ore is transported via water which becomes a slurry. The key factor in this process is to extract the ore using the application of high pressure water to squeeze the slurry through a filter press. See Figure 16.72.

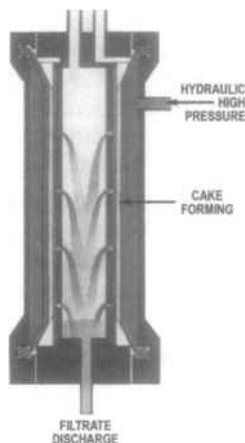


Figure 16.72 Filtration system
Courtesy of RMI Pressure Systems Ltd

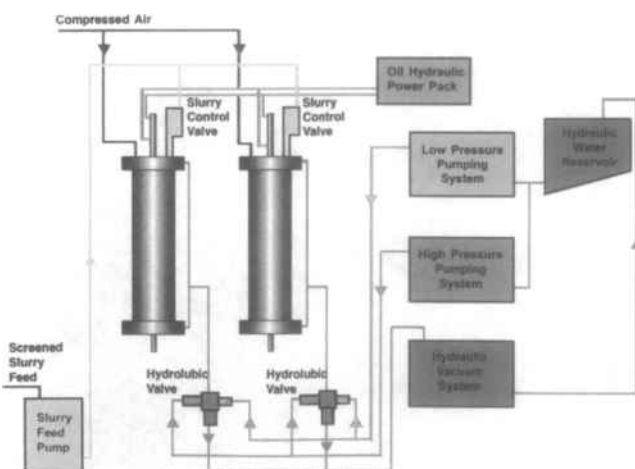


Figure 16.73. Typical tube press flowsheet
Courtesy of RMI Pressure Systems Ltd

Technical application

As mentioned the key factor in the systems design is to remove the ore from the slurry prior to fine filtering. The difficulty arises in that this is generally a medium pressure application up to 100 barg, relative to normal high pressure installations for steelworks applications of 400 barg, meaning that this was completely unsuitable for a normal centrifugal pump system. The overriding challenge was to maintain pump control and system supply via a positive displacement pump system, which is inherently more complex than a standard centrifugal pump system. See Figure 16.73.

The solution

A complete bespoke system was designed based around a standard crankshaft-driven reciprocating pump with a set of accumulators and nitrogen charged back up bottles (See Figures 16.74 and 16.75). The pumps were then fitted with unloading valves and safety devices to ensure that a fine pressure hysteresis of the system was achieved.

In order for the system design to meet these specific criteria, a detailed analysis of system demand was extracted from the user's PLC system. From this data the pump duty was determined, the accumulator sized and the process parameters applied to the system.

These parameters had to ensure that the system achieved and maintained the following:

- The pump unit had to cycle on load-off load, every five seconds.
- The accumulators had to operate within 10% of the system's nominal pressure, with the option that this could be adjusted down to 5%.

The plant in which the system is installed operates 24 hours a day, 7 days a week; therefore there was no room for error in the performance.

After installation

Following installation on site, a number of months were spent monitoring the system, assessing the performance requirements and then adjusting the system capabilities to suit.

One year later, a programme of routine inspection is underway to ensure that the system continues to perform within the re-

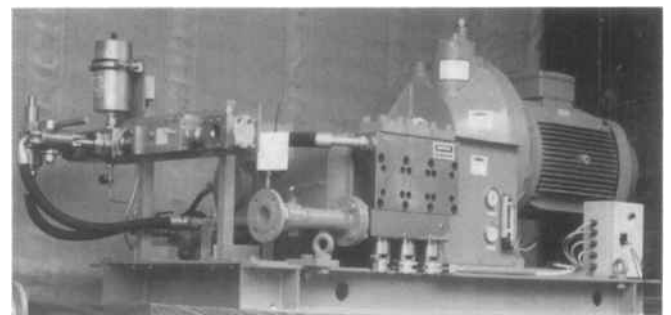


Figure 16.74 The pump unit
Courtesy of RMI Pressure Systems Ltd

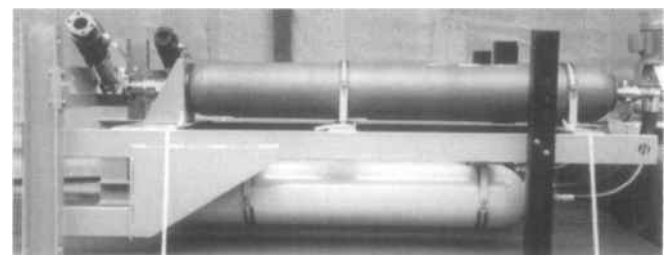


Figure 16.75. Accumulator bank
Courtesy of RMI Pressure Systems Ltd

quirements of the technical criteria laid down and constantly monitor feedback.

Application courtesy of RMI Pressure Systems Ltd

16.24 Boiler feed pump for efficient power station operation

Introduction

With its 40 MW drive rating, this feed pump, known as "The Gentle Giant", was at the time of installation, the largest ever produced. It was built for Unit K, the latest addition to the Niederaussem lignite-fired power station near Cologne in Germany. See Figure 16.76.

The new power station has a power output of 1000 MW and a net efficiency of 43 % making it one of the most modern and efficient stations in the world. To achieve such a performance, all components of the power station unit had to be perfectly matched to the process as a whole. The feed pump provides the total boiler flow without the provision of a back-up unit, and instead relies upon remote telemetry monitoring for condition based monitoring.

Plant outages are every power station operator's nightmare because of the immense costs involved. The pump, therefore, has to be very hard-wearing, insensitive to extreme duty conditions, and provide reliable service for long periods without maintenance. But that isn't all; energy supply companies also expect a very good efficiency. After all, every kW not consumed by the pump – which is in operation around the clock – can be sold to its customers.

Turbine drives pump

The pump is driven by its own steam turbine with continuously variable speed control. The turbine has a power rating of 44 MW and is equipped with two shaft ends, Figure 16.77. One shaft end is directly coupled to the pump. The other, on the opposite side of the turbine, drives a booster pump which supplies

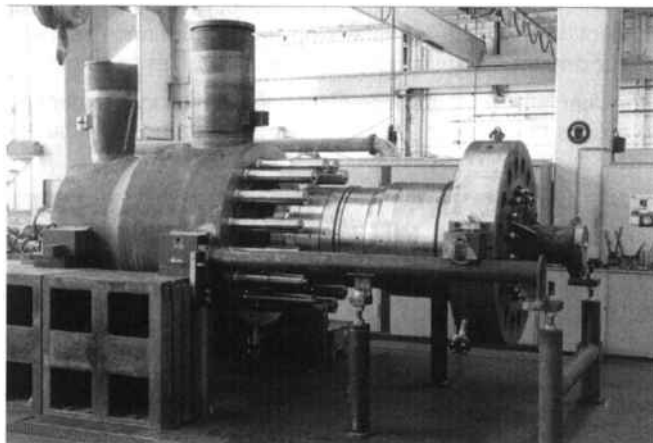


Figure 16.76 Assembly of the feed pump
Courtesy KSB AG

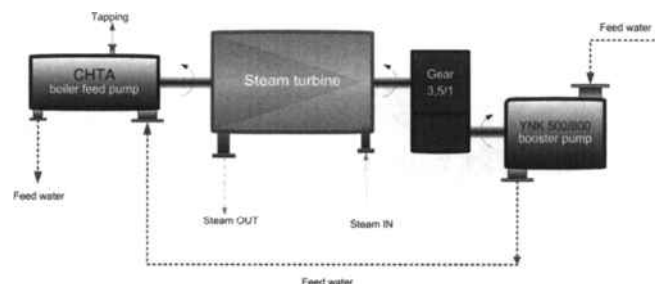


Figure 16.77 Simplified schematic of the steam turbine and the two pumps
Courtesy KSB AG

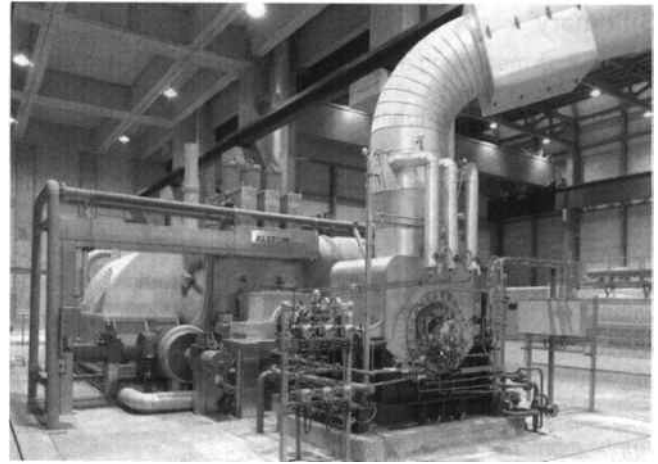


Figure 16.78 A booster pump
Courtesy KSB AG

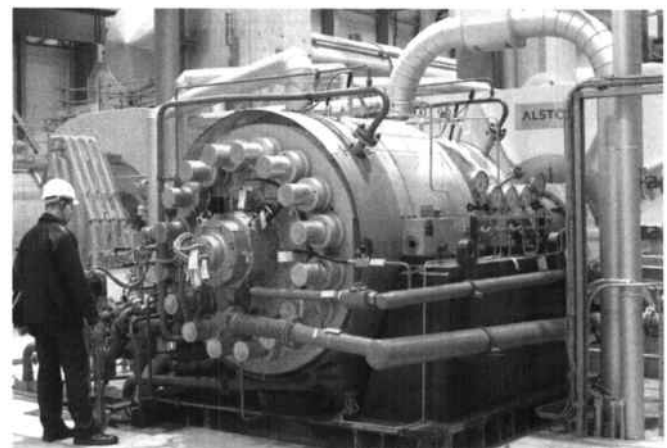
the main pump with the necessary inlet pressure, (see Figure 16.78). The booster is not coupled to the turbine direct but to a gear which reduces the speed by a ratio of 3.5 to 1. Running up and low flow operation are normally taken care of by two electric motor-driven start-up pumps, each with an output of approximately 35% of that of the feed pump. During these phases of operation, the main boiler produces too little steam to operate the feed pump turbine. In exceptional circumstances, the steam needed to start up the pump and run up the turbo-alternator whilst the pump is still cold, can also be supplied from an auxiliary boiler.

Special vane profile

As the pressure in the system can change enormously in response to the operating conditions of the power station unit, the first stage with its impeller is the most sensitive section in every boiler feed pump. The plant operator's specification called for a minimum of 50,000 hours of operation without cavitation-induced wear. To meet this requirement, a special vane profile needed to be developed for the first stage impeller.

Computational fluid dynamic (CFD) modelling was used to design an impeller that would allow the pump to be operated without cavitation across the entire relevant operating range and with a sufficient safety margin from the system's NPSH available.

A number of special components had to be designed to meet the taxing demands made on the pump set. See Figure 16.79. The floating ring seal is a case in point. This type of seal is very reliable, even at peak running speeds of 50 m/s and more, which are common on high specific speed pumps. Other exceptional features of the seal are its thermal characteristics and the way these positively affect the pump's operation. This will be discussed later.



Hydraulic design

At the duty point, the main feed pump is expected to have the following performance data:

Flow rate = 2898 m³/h ($\dot{m}$ = 698 kg/s)
 Differential head = 3361 m (Δp = 285.7 bar)
 Inlet temperature = 198.4 °C
 Speed = 4620 rpm
 Power = 26.47 MW
 Efficiency = 86.9 %

At the so-called "TÜV point", when the boiler relief valve starts to lift, the pump set reaches a maximum speed of 5217 rpm. It delivers hot water at a rate of 893 kg/s and has a power input of just under 42 MW (around 2 MW of which are required for the booster). The total head rise is divided among five stages, with a tapping downstream of the first stage.

As far as the hydraulic designs of the impeller and the individual stages are concerned, this gives us a specific speed of:

$$n_q = n \cdot \frac{\sqrt{Q}}{H_{St}^{0.75}} = 31 \quad \text{Equ 16.13}$$

where:

n = speed (min⁻¹)
 H = head (m)
 Q = flow (m³/s)

In terms of efficiency, total construction effort and cavitation properties, this value is very favourable for a high-pressure pump of this kind. From the design point of view, the hydraulic elements of the pump can be regarded as unproblematic. The geometries of the impellers and diffusers of stages two to five were taken from time-tested older pump models and converted to the required sizes on the basis of the Affinity Laws. There were some minor modifications to be made to the hub to accommodate the increase in shaft diameter on account of the higher drive rating.

The first stage impeller

The most "critical" pump element from the point of view of fluid dynamics is the first stage impeller, which differentiates between the first of several identical stages and a special suction impeller design. The specification stipulated a guaranteed minimum period of operation of 50,000 hours without cavitation-induced wear. Cavitation, or rather the damage it does in the form of cavitation erosion and corrosion, is a major area of concern for the operation of turbomachinery.

Numerically speaking, the phenomenon is expressed by the NPSH value in pumps. It is governed by the following relationship:

$$NPSH_a \text{ (system)} \geq NPSH_r \text{ (pump)} \quad \text{Equ 16.14}$$

The $NPSH_a$ value denotes the energy made available by the system immediately upstream of the pump. It is expressed in metres and already takes into account the pumped liquid's vapour pressure, which is why it is commonly referred to as Net Positive Suction Head Available. It must not be confused with the $NPSH_r$, Net Positive Suction Head Required, value of the pump, i.e. the energy required at the pump's inlet to avoid cavitation altogether or at least prevent it from damaging the pump internals. The $NPSH$ "required" by a pump depends on the properties of the impeller material and the velocity of the flow in the impeller inlet area. The latter results from the circumferential speed u_{11a} at the outer impeller inlet diameter, the tip speed of the eye. It is a linear function of the speed of rotation, Figure 16.80:

$$u_{11a} = \pi \cdot D_{11a} \cdot n \quad \text{Equ 16.15}$$

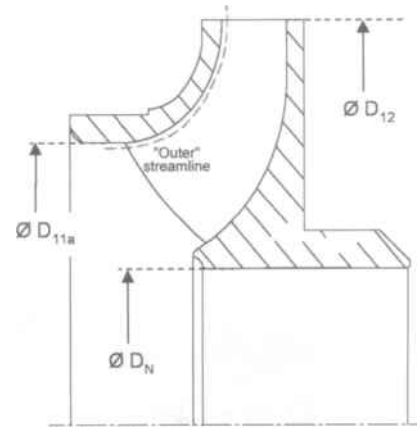


Figure 16.80 First-stage impeller (schematic)
 Courtesy KSB AG

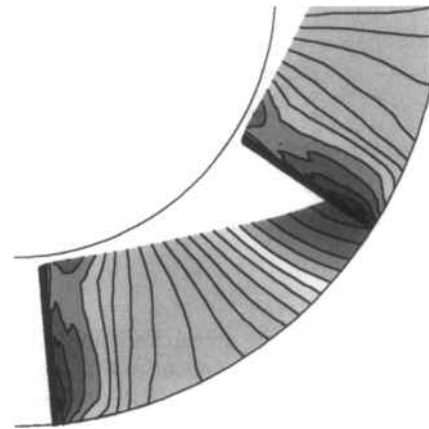


Figure 16.81 Simulated flow patterns inside an impeller
 Courtesy KSB AG

The tip speed of the eye has a major influence on the so-called material loss rate VA , which is an indicator of the erosion phenomena caused by cavitation. Previous experience has shown that the material loss rate will become extremely high at tip speeds (u_{11a}) of more than 70 metres per second. Under these conditions, even impellers made of high grade materials will soon begin to show signs of damage if subject to the slightest cavitation. So, in order to guarantee the lifetime specified, the designer must make sure that the pump set can be operated at the main duty points without any risk of cavitation:

$$NPSH_a > NPSH_r = NPSH \quad \text{Equ 16.16}$$

Consequently, the main criterion for designing the first stage impeller is to develop a geometry that will ensure non-cavitating pump operation.

Simulating flow in the impeller

At the blueprint stage, the design properties of the impeller were demonstrated by means of computational fluid dynamics. The findings were then verified experimentally by cavitation testing. The design tool used for analysis is a method based on three-dimensional Euler equations. It simulates the flow patterns inside the impeller and provides information on the local pressures and velocities occurring at any point of the impeller passage, Figure 16.81. The method is known to provide accurate data for this type of project and is a very good compromise between speed and reliability. Figure 16.82 shows an example of this kind of analysis.

After a series of optimisation runs produced the final contour, the "ideal" geometry has to be translated into the actual component with the highest possible degree of accuracy. To do this, the inlet areas of oversize vane blanks are reduced to their final dimensions using electric discharge machine tools. Another part of the optimisation process reduces the interaction be-

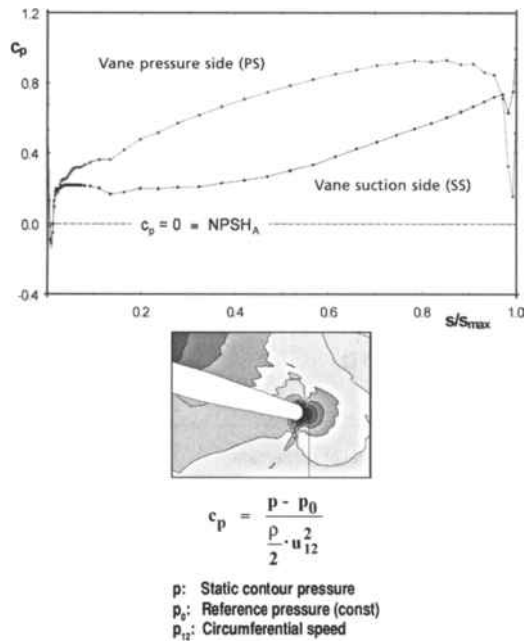


Figure 16.82 Computed pressure distribution (example)
Courtesy KSB AG

tween the impellers and the stationary diffuser so that little or no vibration is produced.

Cavitation testing

To verify that the suction stage impeller actually gives non-cavitating operation at the “critical” duty points, the impeller was installed and tested as a single-stage pump on a cavitation test bench, Figure 16.83, specially built for this purpose. On the inlet side of the impeller the test arrangement was fitted with a replica of the original suction elbow which featured a Plexiglas window to allow the flow behaviour to be studied close up. The observed NPSH values had a sufficient safety margin from the NPSH_A values and agreed very well with the computed values, Figure 16.84. The plotted NPSH_A values mainly resulted from the head of the booster pump, converted to the conditions

of the test arrangement, whose main task it is to increase the pressure to the level required by the high-speed main pump.

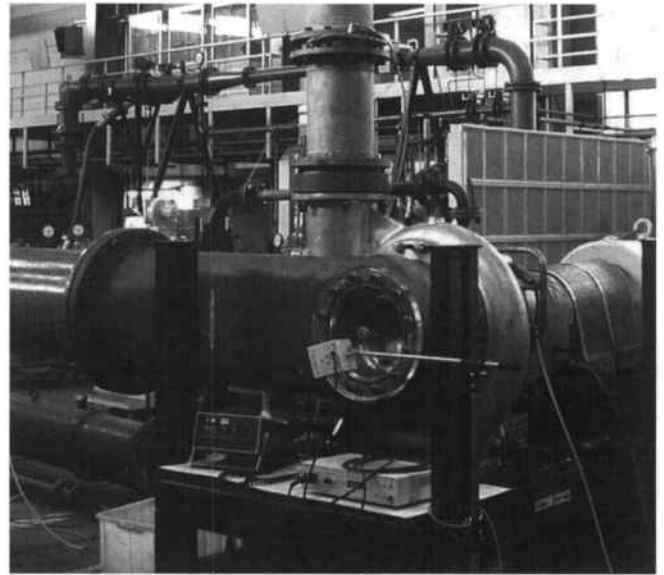
The rotor

The power transmitted by the drive turbine is transmitted via the pump shaft to the impellers. These are mounted on the shaft by way of a rigid and wear-resistant connection, see Figure 16.85, part 1.

The pressure distribution around the impeller gives rise to a hydraulic axial thrust, Figure 16.86, which is transmitted to the shaft by means of a separate split ring for every impeller. The axial thrust, which increases in intensity from one impeller to the next and can eventually reach a maximum value of 11.5 MN, is reliably balanced by a doubled drum, Figure 16.85, part 2. Thanks to its hydraulic properties, the double drum is capable of permanently reducing the forces acting on the thrust bearing. The thrust bearing is thus protected against overloading even in the event of sudden transient load changes.

The shaft bearings

Grooved multi-lobe plain bearings were selected as radial bearings based on the positive previous experience with this type of bearing in terms of load-carrying capacity and dynamic properties, Figure 16.85, part 6. Like the thrust bearing, the plain bearings are lubricated with pressurised oil supplied from the turbine's oil supply system. The tilting-pad thrust bearing for load in either axial direction, Figure 16.85, part 7, is reliably protected against a sudden reverse of the residual axial thrust. Together with the balancing properties of the double drum, the



bearing effectively protects the pump against overloading and

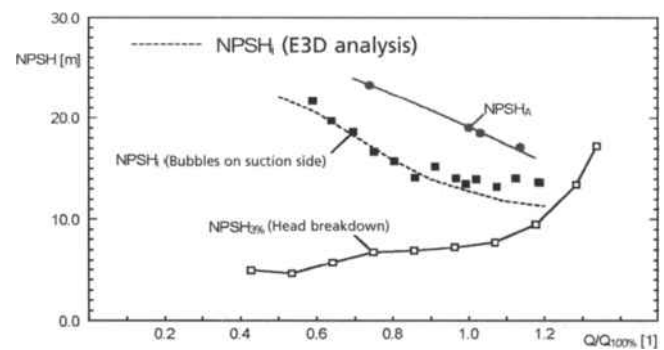


Figure 16.84 Results of a “bubble visualization” test
Courtesy KSB AG

the harmful effects of sudden load transients.

The stationary components

One of the most striking things about the feed pump on first sight is probably the pressure boundary. It consists of a forged barrel casing, Figure 16.85, part 8, and a cover, Figure 16.85, part 9, which – securely located by substantial studs and nuts, Figure 16.85, part 10 – is designed to retain the internal pump pressure.

The nuts are tightened with a hydraulic tensioning tool. This allows the nuts to be tightened without applying torsional shear stresses or bending stresses to the studs. These fasteners, which have to withstand higher loads than any others in the entire pump, can thus be designed with the required reliability.

Taking on 36.75 MN!

The pressure forces generating the axial thrust on the rotor also have an effect on the stationary parts. For the main joint fasteners, which have to secure the cover against the internal pressure, this means they have to withstand a maximum load of 36.75 MN! A spring element, the compensator, provides a sufficient level of preloading of the internal components to keep them locked in place even during a phase of low internal pressure. It also compensates the different degrees of longitudinal expansion of the pump internals and barrel as a result of the uneven temperature distribution typically occurring during transient load changes. In a thermal shock, these differences can measure several millimetres in length, which have to be accommodated without affecting the installation's availability or causing damage.

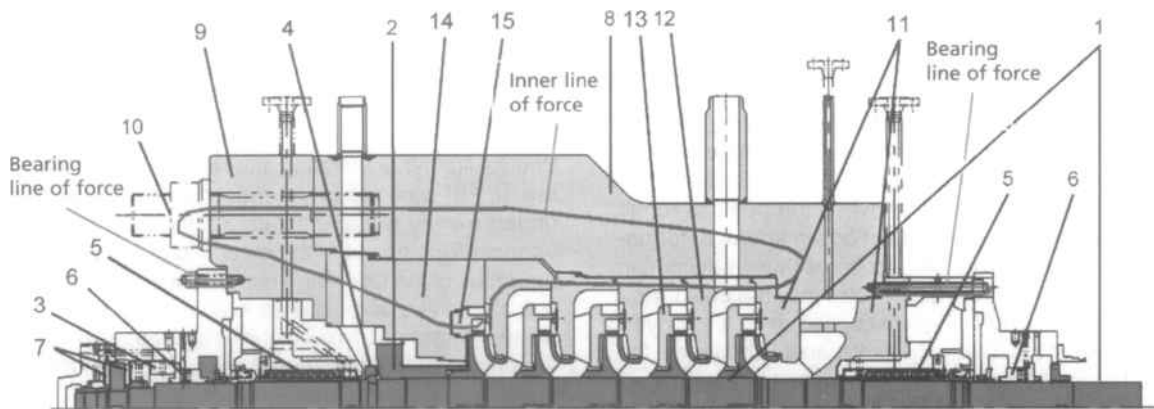


Figure 16.85 Main lines of force acting on the stationary components
Courtesy KSB AG

Temperature differences can also occur during start-up or as a result of an emergency shutdown. The internal hot water will stratify causing the top half to be much hotter than the bottom half and will cause jamming of the shaft and floating ring seals. The drive turbine is, therefore, equipped with a small electric motor to keep the pump rotating or barring, at approximately 100 revolutions per minute. As the pump gains speed, the internal pressure increases the rigidity of the pump components. The lines of action of the internal forces are crucial for the vibration characteristics of the pump running at full load. As well as a low-excitation hydraulic system an undivided line of action of the internal forces is of major importance. If the bearing forces can be separated from the hydraulic forces on entering the barrel (See the lines of force demonstrated on Figure 16.85.) this will greatly benefit the pump's operating behaviour.

One of the advantages of the low vibration level was that the pump produced so little noise that the originally planned sound-absorbing cover proved unnecessary. The static seal elements required to seal the pressure from atmosphere are designed as profile rings capable of sealing 500 bar(g) pressure maximum. Their sealing action is directly linked to the surrounding system pressure. It causes the sealing lips to be pressed against the components to be sealed. No other forces are needed to achieve the sealing effect. A further advantage of this seal type is that it does not reduce the joint pressure other parts need for their sealing function, for example the metal-to-metal sealing of the stage casings.

Shaft seals

In recent years, many power station owners and operators have learned the hard way that of all the components of a feed pump, shafts seals in particular are highly sensitive assemblies. They can make or break the availability of an entire power station. Since floating ring seals have been giving many years of reliable service in the older units of the Niederaussem power station, this seal type was selected for the new turbine-driven feed pump. In the seal, the pressure is relieved from suction pressure to atmospheric pressure along a multistage throttling distance made up of "floating rings". Depending on the pump's duty point, the pressure drop can be as high as 40 bar. As the pumped liquid flows through the annular gap between shaft and floating ring, it assumes a "bearing quality" which causes the ring to float, preventing physical contact.

To stop the flow of hot water from the pump into the seal from evaporating, and to prevent the throttling rings from losing their bearing quality as a consequence, the system has to be sealed with cold condensate. The condensate is injected at the end of the first throttling section. The injection rate is controlled by a regulating valve positioned at the inlet. As the cold condensate is mixed with the hot feed water from the pump, the heating rate of the total flow of leakage can be measured and the measured value taken as a parameter for controlling the valve. The leak-

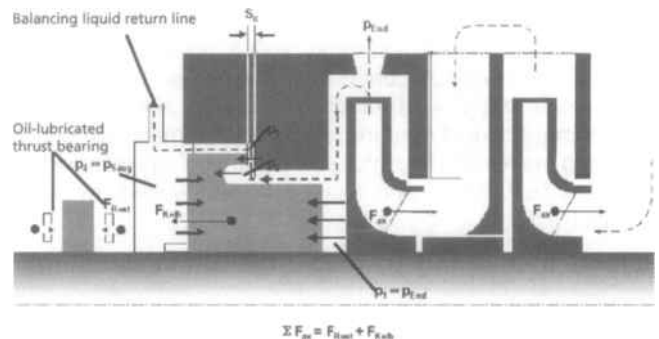


Figure 16.86 Axial thrust balancing
Courtesy KSB AG

age flows into a tank with level monitoring and is fed from there into the condensate system. Two 100 % pumps (one duty, one standby) supply the seals with barrier condensate, even if either pump fails. A simplified schematic of the barrier condensate cycle of the floating ring seal is shown in Figure 16.87.

Planned maintenance

Whenever the pump shaft is turning, i.e. even when it is in barring mode, the barrier condensate system has to be in operation as well, because that it is the only way to stop the floating rings from coming into contact with the rotating shaft. After all, with planned maintenance intervals of between three and five years, the shaft seal system has to be absolutely dependable. During the commissioning phase of the feed pump, the thermal characteristics of this shaft seal type proved particularly valuable. As there is always a liquid flow in axial direction through

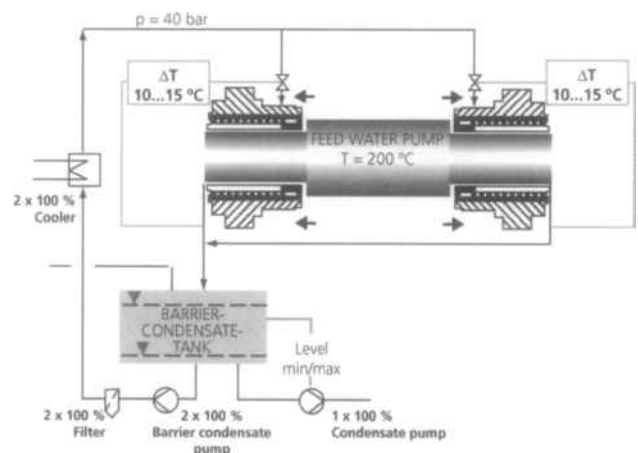


Figure 16.87 Barrier condensate cycle of the floating ring seal
Courtesy KSB AG

the section of the shaft where the floating ring seal is located, hardly any thermal stratification develops in this area.

A system equipped with a mechanical seal would respond differently. It would require heating jacket and circulation cooling, and the cold condensate, 60 °C, used by both cooling systems would continually create new temperature stratifications on being mixed with the hot feed water, 200 °C. Temperature differences of this kind develop above all when the pump is run in barring mode and may cause shaft deflection and/or deformation of the pump casing. The joint action of these effects can lead to such severe distortion that the rotor may rub against the casing in less than a minute. Typical consequences are overloading and failure of the barring gear. When this happens, the pump has to be cooled down to a much lower temperature so that the deformation is reduced and the rotor can turn without touching the casing. These processes are of paramount importance for the availability of a main feed pump.

A “well-tempered” pump

An event during commissioning demonstrated the excellent thermal characteristics of this truly “well-tempered” pump. Due to a fault in the turbine’s control logic, the pump – filled with hot feed water at 180 °C – did not run for all of 31 minutes. After that the automatic control system inexplicably returned it to service in barring mode. And the rotor started turning again smoothly! An incident of this kind would have normally caused any pump to seize!

Remote monitoring accompanies commissioning

At the request of the owner/operator, the pump unit is monitored by means of a complex telemonitoring system comprising more than 50 pressure, temperature, vibration level and shaft orbit sensors. These sensors transmit the data collected to the teleservice centre direct where they are stored in a database, ready for retrieval any time the specialists need them. Despite extensive prior computations, pump units of this size always require practical testing to develop and calibrate the most favourable models for starting up and stopping the pump.

These models serve to optimise the cold and hot running phases in the power station, which improves the cost efficiency of the plant without jeopardising its availability. Based on the data supplied by the sensors, the pump designers study phenomena like thermally-induced stresses in and deformations of pump components, as well as their effects on the pump’s run-

ning characteristics. This information aids condition-based maintenance and enables the pump manufacturer and plant operator jointly to determine the maximum permissible duty conditions of pump and peripherals.

Summary

With its 40 MW drive rating, the Niederaussem feed pump (Figure 16.88) was one of the most demanding of developments undertaken by its manufacturers at the time. Specially designed vane profiling provided the means to guarantee non-cavitating operation of the first-stage impeller, which was proven by theoretical analysis and experimental tests. The system pressure, the temperatures involved and its high speed of rotation subject the pump set to extreme mechanical and thermal stresses.

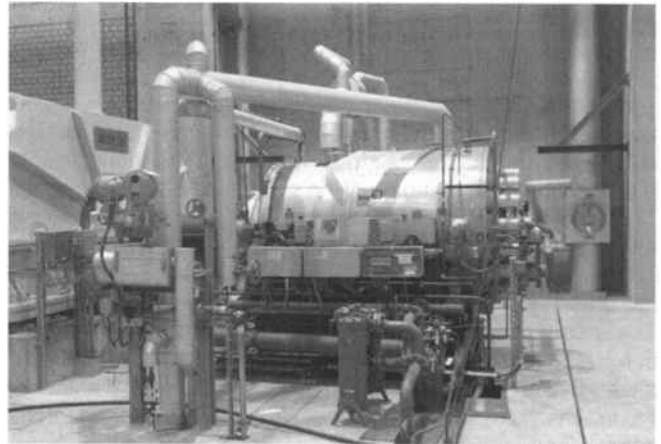


Figure 16.88 Side view of the boiler feed pump
Courtesy KSB AG

As well as the bearing arrangement and the method of axial thrust balancing, the real technological highlight of the pump is the shaft seal, a sophisticated floating ring seal. Intensive in-house testing and data obtained during the commissioning phase at the power station provided ample proof that the pump met all of the technical and economic requirements originally specified.

Application courtesy of KSB AG

Based on a technical paper presented by: Dipl-Ing Thomas Elsässer KSB AG, Dipl-Ing Bernhard Brecht KSB AG, Dr.-Ing Sven Baumgarten KSB AG, Dr Kirk Kollmar KSB AG

Standards, units & conversions 17

17.1 Standards

- 17.1.1 General
- 17.1.2 Issuing authorities
- 17.1.3 Pumps
- 17.1.4 Safety
- 17.1.5 Reliability and operational life
- 17.1.6 Dimensions and performance
- 17.1.7 Vibration and noise
- 17.1.8 Forces and moments on connections
- 17.1.9 Components
- 17.1.10 Performance testing
- 17.1.11 Hygiene
- 17.1.12 Electromagnetic pollution

17.2 SI, The International System of Units

- 17.2.1 Brief history of unit systems
- 17.2.2 Method of expressing symbols and numbers
- 17.2.3 Multiples of SI units
- 17.2.4 Derived units

17.3 Conversion factors for SI units

- 17.3.1 Plane angle
- 17.3.2 Length
- 17.3.3 Area
- 17.3.4 Volume

17.3.5 Time

- 17.3.6 Linear velocity
- 17.3.7 Linear acceleration
- 17.3.8 Angular velocity
- 17.3.9 Angular acceleration
- 17.3.10 Mass
- 17.3.11 Density
- 17.3.12 Force
- 17.3.13 Torque
- 17.3.14 Pressure, stress
- 17.3.15 Dynamic viscosity
- 17.3.16 Kinematic viscosity
- 17.3.17 Energy
- 17.3.18 Power
- 17.3.19 Flow
- 17.3.20 Temperature

17.4 Other conversion factors

- 17.4.1 Hardness
- 17.4.2 Material toughness

17.5 Normal quantities and units used in pump technology

17.6 Useful references

17.1 Standards

17.1.1 General

Standards were initially applied to the finished dimensions of machine components to ensure easy replacement of worn or broken parts. The scope and activities of standards have been successively extended to cover the complete machine not only with regard to dimensioning but also to such parameters as performance, reliability and safety.

Within the pump industry standardisation has developed in a similar fashion and today there are a considerable number of standards and regulations. There are also a large number of new standards which are in the process of preparation and old standards in the process of revision. Some standards have legal authority and can be enforced by the process of law; these are mostly restricted to safety requirements.

Most standards are issued for guidance. If, for example, one issued an enquiry to 10 pump manufacturers which simply stated "five pumps required for 100 m³/h at 100m ΔH" one would receive ten quotations for 10 totally different pumps. Comparison between the quotations would be difficult or impossible. Selection of the best pump would be dubious without very detailed design and construction information on each pump. The solution to the problem is to issue a specification with the enquiry detailing the important characteristics required. To avoid the necessity of every purchaser writing their own specifications, groups were formed to write a single common specification for certain areas of application.

Because of the diversity of issuing authorities, the style and concept of standards is not uniform. CEN has decided upon rigorous control of all aspects of standards such as presentation, structure and content. CEN has produced a manual for all concerned with standard writing and it is worthwhile reviewing for the structure and content requirements.

CEN standards consist of requirements; these are basically statements controlling design, construction and use. Requirements must be verifiable. A competent person, inspecting the equipment/installation/service, must be able to see that a requirement has been met or not. For example, if a standard specifies that pumps must be painted with a minimum thickness of 200 μm, an inspector can measure the paint thickness and say categorically that it complies or not. If an inspector visits a manufacturer's works to witness all stages of manufacture and testing and the standard specifies "Equipment shall be suitable for three years uninterrupted operation", what can the inspector do? Standards cannot address concepts such as ruggedness, durability, heavy-duty; which are all subjective and cannot be verified.

17.1.2 Issuing authorities

In principle, a standard can be issued by anyone. In order that the standard shall carry some influence, however, the issuing organisation should be one that is recognised by both the manufacturer and the user of the object to be standardised. It is therefore normal practice for new standards to be developed by these three parties. The organisations which issue standards consist of the following categories:

- International standard organisations
- Geographic country group standard organisations
- National standard organisations

International standard organisations require the cooperation and support of many countries. As the world becomes, effectively smaller, more and more international trade transactions will be regulated by international standards.

Geographic country group organisations are made up of countries, usually close to each other, which form an economic trad-

ing block. This type of cooperation is becoming popular and could result in an expansion of issuing authorities.

Another type of document is frequently used to assist the purchasing of pumps — a specification. A specification is very similar in most respects to a standard but does not necessarily have the same rigorous editorial controls. Specifications are issued by:

- Trade societies and associations
- Corporations, large companies, government departments
- Classification societies (insurance companies)
- Certification authorities (insurance companies)

Trade societies and associations are groups of companies which share a common interest. For example, utility suppliers, water or electricity, could form a trade association with pump and valve manufacturers and firms of consultants which regularly design systems. Together they agree a common approach to the design and operational problems of pumps/valves and write specifications to improve reliability. All members use the same specification for the same items.

Corporations, large companies and government departments issue specifications to control important features, design and/or function. Chemical companies, who develop new manufacturing processes, often issue specifications to regulate size, speed and rating of important equipment.

Classification societies are generally one, or more, insurance companies who issue rules for design and construction. This type of specification is used for marine installations, ships and offshore platforms, and the most notable authorities are: Lloyds Register, Det Norske Veritas and the American Bureau of Shipping. If a design standard requires a component to be 20mm thick but the specification requires 25mm it is the specification which takes precedence. If a ship owner tries to insure a ship, the first question asked is "Can I see your Classification Certificate?".

Certification authorities are very similar to classification societies but work in conjunction with the purchaser on large projects which have some degree of risk or hazard for the purchaser's capital investment or personnel safety. Certification authorities are regularly used for large petrochemical installations and offshore platforms. Special standards or specifications are not always issued. Experienced inspectors scrutinise and witness all relevant aspects of equipment; design, raw material, construction, testing, safety; and issue a certificate, if completely satisfied, when the equipment is ready to be dispatched. Purchase orders usually state the inspectors' decision is final irrespective of specification or standard requirements.

Specifications may be written as a general purpose document which can be used repeatedly. Some specifications are written for a specific contract and are not reusable. A specification may be written by one person and not subject to scrutiny or editorial control. Specification writers may not appreciate the concept of "requirements" and ask for "functions" which are not verifiable at the manufacturer's works. Failures at site are often difficult to attribute because of the lack of discipline of the operating staff.

Standards and specifications form part of the purchase order and are binding on all parties. Good standards and specifications assist the purchaser and improve the purchasing process. Standards and specifications can be very restrictive and inhibit technological advances or prevent the use of the most appropriate equipment. Standards and specifications are not necessarily useful to purchasers who do not understand the equipment or the full implications of meeting requirements.

The number of issuing authorities can therefore be very large and varying which often presents difficulties when developing new standards. Since there are many conflicting interests, es-

pecially when applied to international standards, the result is often a compromise with which none of the involved parties is completely satisfied. The advantages to be gained by the specification and general acceptance of standards and regulations however usually outweigh the disadvantages.

CEN issues standards to control trade within the EEC and EFTA, (European Free Trade Association). EFTA is an inter-governmental organization. Its members are Iceland, Liechtenstein, Norway and Switzerland. From 1995, it has not been possible to use national standards for trade between member countries; ENs or ISOs are used. ISO is issuing new standards to control world trade. ISO discussed with all standards organisations and trade associations the rationalisation of worldwide standardisation. ISO and CEN have an understanding and try not to duplicate standards.

Standards and specifications usually contain a immunity clause. Strict compliance with any standard does not ensure or guarantee success. Standards are written with the best of intentions with the best information available. It is the responsibility of the user of the standard to ensure the standard's requirements are compatible with the equipment and its operation in each individual case.

Some of the most important bodies for issuing standards impacting on the manufacture and use of pumps are shown in Table 4.4.

	Body	Standards
ANSI	American National Standards Institute	ANSI
ASME	The American Society of Mechanical Engineers	ASME
ASTM	The American Society for Testing Materials	ASTM
BSI	British Standards Institution	BS
CEN	Comité Européen de Normalisation	EN
DIN	Deutsches Institut für Normung	DIN
ISO	International Organisation for Standardisation	ISO

Table 17.1 Standards issuing organisations for pumps

There are other standards which do not refer to pumps directly but contain essential information for both users and manufacturers, see Table 4.5.

	Body	Standards
ADR	See NOTE below	ADR
CENELEC	Comité Européen de Normalisation Electrotechnique	HD
EPA	The Environmental Protection Agency (USA)	
HSE	The Health and Safety Executive (UK)	EH
IEC	The International Electrotechnical Committee	IEC
NACE	The National Association of Corrosion Engineers (USA)	MR
NFPA	The National Fire Protection Agency (USA)	NFPA
OSHA	Occupational Safety and Health Administration (USA)	OSHA

Table 17.2 Other useful Standards organisations

NOTE: ADR is a very special standard. It is not published by a multinational standards authority but it is subject to agreement by many national authorities who publish their own copy.

17.1.3 Pumps

ANSI B73.1 End-suction centrifugal pumps for chemical applications.

ANSI B73.2 Inline centrifugal pumps for chemical applications.

ANSI B73.3 Sealless pumps.

API 610 Centrifugal pumps for petroleum, heavy-duty chemical and gas industry services.

API 674 Positive displacement pumps - reciprocating.

API 675 Metering pumps.

API 676 Positive displacement pumps - rotary.

API 685 Sealless Centrifugal Pumps for Petroleum, Heavy Duty Chemical, and Gas Industry Services.

BS 1394 Stationary circulating pumps for heating and hot water service systems; Part 2: Specification for physical and performance requirements.

BS 4082 Specification for external dimensions for vertical inline centrifugal pumps; Part 1: "I" type close-coupled.

BS 4082 Specification for external dimensions for vertical inline centrifugal pumps; Part 2: "U" type close-coupled.

BS 5555 SI units and recommendations for the use of their multiples and of certain other units.

BS 6785 Code of practice for solar heating systems for swimming pools.

EN 733 End-suction centrifugal pumps, rating 10 bar with bearing bracket - Nominal duty point, main dimensions, designation system.

EN 734 Side channel pumps PN 40 - Nominal duty point, main dimensions, designation system.

EN 735 Overall dimensions of rotodynamic pumps - Tolerances.

EN 1028-1 Fire fighting pumps; Part 1: Requirements for fire fighting centrifugal pumps with primer "CE".

EN 1151 Pumps; Rotodynamic pumps; Circulation pumps having an electrical effect not exceeding 200 W for heating installations and domestic hot water installations; Requirements, testing, marking "CE".

EN 12157 Centrifugal pumps - Coolant pumps for machine tools - Nominal flow rate, dimensions (similar to BS 3766).

EN 12262 Rotodynamic pumps - Technical documents - Terms, delivery range, layout.

EN 12723 Liquid pumps; General terms for pumps and installations; Definitions, quantities, symbols and units.

EN 14343 Rotary positive displacement pumps - Performance tests for acceptance.

EN 22858 End-suction centrifugal pumps (rating 16 bar) - Designation, nominal point and dimensions (ISO 2858)(was BS 5257).

EN 23661 End-suction centrifugal pumps - Baseplate and installation dimensions (ISO 3661).

EN 25199 Technical requirements for centrifugal pumps; Class II (ISO 5199)(was BS 6836)(chemical applications).

EN 28849 Small craft - Electrically operated bilge-pumps (less than 50V dc)(ISO 8849).

EN ISO 14847 Rotary positive displacement pumps - General requirements.

EN ISO 16330 Reciprocating positive displacement pumps and pump units. Technical requirements.

EN ISO 21049 Shaft Sealing Systems for Centrifugal and Rotary Pumps. (API 682)

HI 5.1 - 5.6 Sealless pumps.

ISO 1000 SI units and recommendations for the use of their multiples and of certain other units.

ISO 3069 End-suction centrifugal pumps - Dimensions of cavities for mechanical seals and for soft packing.

ISO 3661 End-suction centrifugal pumps - Baseplate and installation dimensions.

ISO 5198 Centrifugal, mixed-flow and axial pumps - Code for hydraulic performance tests - Precision grade

ISO 9905 Technical specification for centrifugal pumps; Class I (heavy-duty refinery applications)(was BS 7784).

ISO 9906 Rotodynamic pumps - Hydraulic performance acceptance tests - Grades 1 & 2.

ISO 9908 Technical specification for centrifugal pumps; Class III (industrial applications)(was BS 7736).

ISO 13709 Centrifugal pumps for petroleum, heavy-duty chemical and gas industry services (API 610 8th ed)

ISO 13710 Petroleum, petrochemical and natural gas industries - Reciprocating positive displacement pumps. (API 674).

ISO 15783 Sealless rotodynamic pumps - Class II - Technical specification.

PD ISO/TR 17766 Centrifugal pumps handling viscous liquids - Performance corrections.

ISO 24490 Cryogenic vessels - Pumps for cryogenic service.

Pump standards being developed:

Pitot tube pumps by the Hydraulic Institute - Draft being reviewed.

Hand-operated water pumps for wells by ISO.

17.1.4 Safety

The standards and regulations applying to safety are primarily concerned with the way in which pumps and systems shall be designed and constructed so as to avoid "harm". Harm is defined in EN1050 as "physical injury and/or damage to health or property". Protection of the environment seems to have been overlooked! Protection of the environment is included in prEN 12690.

The safety of all machinery in Europe is covered by the Machinery Directive. The Directive requires that all manufacturers shall make machinery, by design and construction, as safe as possible. If any hazards will occur during operation or maintenance the manufacturer must highlight these problems and state what precautions must be taken. Pumps and pump units are included in the European Machinery Directive and specific European Standards must be followed to ensure pump safety. Compliance with the following standards is a prerequisite if the "CE" mark is required.

IEC 60079, EN 60079 Electrical apparatus for explosive gas atmospheres (other than mines or explosives) —

Part 0 - General requirements.

Part 1 - Flameproof enclosure 'd'.

Part 2 - Pressurisation 'p'.

Part 5 - Powder filling 'q'.

Part 6 - Oil immersion 'o'.

Part 7 - Increased safety 'e'.

Part 11 - Intrinsic safety 'i'.

Part 15 - Type of protection 'n'.

Part 18 - Encapsulation 'm'.

Part 19 - Repair and overhaul for apparatus used in explosive atmospheres.

EN 292-1 Safety of Machinery; Basic concepts, general principles for design;

Part 1: Basic terminology, methodology.

Part 2: Technical principles and specifications.

EN 294 Safety of machinery; Safety distances to prevent danger zones being reached by the upper limbs.

EN 349 Safety of machinery; Minimum gaps to avoid crushing of parts of the human body.

EN 418 Safety of machinery; Emergency stop equipment, functional aspects; Principles for design.

EN 563 Safety of machinery; temperature of touchable surfaces; ergonomic data to establish temperature limit values for hot surfaces.

EN 626 Safety of machinery; Principles for machinery manufacturers on the reduction of risk to health from hazardous substances emitted by machinery.

Part 1: Principles and specifications for machinery manufacturers.

Part 2: Methodology leading to verification procedures.

EN 809 Pumps and pump units for liquids; Common safety requirements.

EN 894 Safety of machinery; Ergonomic requirements for the design of displays and control actuators;

Part 1; Human interactions with display control actuators.

Part 2; Displays.

Part 3; Control actuators.

EN 953 Safety of machinery; General requirements for the design and construction of guards (fixed, movable).

EN 1037 Safety of machinery; Prevention of unexpected start-up.

EN 1050 Safety of machinery; Risk assessment.

EN 1127-1: Explosive atmospheres - Explosion prevention and protection - Part 1: Basic concepts and methodology

EN 1829 High pressure cleaners - High pressure water jet machines - Safety requirements

Part 1: General description

Part 2: Hoses, hose lines and joints for high pressure cleaners, high pressure water jet machines and water jet cutters as well as safety devices to safeguard joints for hose lines.

EN 12162 Liquid pumps - Safety requirements - Procedure for hydrostatic testing

EN 12462 Biotechnology - Performance criteria for pumps

EN 12690 Biotechnology - Performance criteria for shaft seals.

EN 13386 Liquid pumps - Submersible pumps and pump units - Particular safety requirements.

EN 13951 Liquid pumps - Safety requirements - Agrifoodstuffs equipment; Design rules to ensure hygiene in use

EN 50081 Electromagnetic compatibility (EMC); Generic emission standard;

Part 1: Residential, commercial and light industry.

Part 2: Industrial, environment.

EN 50082 Electromagnetic compatibility (EMC); Generic immunity standard;

Part 1: Residential, commercial and light industry.

Part 2: Industrial, environment.

EN 60204-1 Safety of machinery; Electrical equipment of machines; Part 1: General requirements.

EN 60335 Safety of household and similar electrical appliances;

Part 2-2 Particular requirements for vacuum cleaners and water-suction cleaning appliances.

Part 2-21 Particular requirements for storage water heaters.

Part 2-41 Particular requirements for electric pumps for liquids having a temperature not exceeding 35°C.

Part 2-51 Particular requirements for stationary circulation pumps for heating and service water installations.

Part 2-55 Particular requirements for electrical appliances for use with aquariums and garden ponds.

Part 2-60 Particular requirements for whirlpool baths and similar equipment.

Part 2-69 Particular requirements for wet and dry vacuum cleaners, including power brush, for industrial and commercial use.

Part 2-79 Particular requirements for high pressure cleaners and steam cleaners.

Part 2-105 Particular requirements for multi-functional shower cabinets.

ISO 3864 Safety colours and safety signs.

ISO 8846 Small craft - Electrical devices - Protection against ignition of surrounding flammable gases

Other standards impact on CE compliance and these are indicated as CE where listed. Obviously compliance with any particular European standard specifying technical requirements for a specific pump type is necessary.

Europump Guideline 2000-08 Draft specification on the safety of electrical, submersible motors.

The general principles to be used in the design of complete installations are given in many standards and guidelines. The factors which should be considered include:

- Access
- Dust/gas hazards
- Fire fighting
- Noise
- Proximity of adjacent property
- Redundancy of equipment
- Separation of safety equipment from process equipment

BS 5908 covers fire precautions for chemical and similar installations.

BS 8005 Part 2 gives guidance on the design and construction of pumping stations and pipelines for sewage.

The hazards posed by substances are given in:

EH 40/99 Occupational exposure limits

FPA 325M Fire hazard properties of flammable liquids, gases and volatile solids

NFPA 704 Identification of the fire hazards of materials

ADR European agreement concerning the International carriage of dangerous goods by road.

An important factor in applying safety considerations is the ability of the system to withstand pressure. Pumps, pipes, valves and flanges etc. are therefore constructed to withstand specific pressure ratings associated with temperature. The pressure/temperature ratings for flanges for pipes, valves and fittings etc. can be found in:

ANSI B16.1; ANSI B16.24; ANSI B16.42; ANSI B16.47; ANSI B16.5; ANSI B93.75; BS 10; BS 1560; BS 3293; BS 4504; ISO 7005

The design of pressure vessels and associated pressure/temperature ratings can be found in:

ASME VIII; BS PD 5500; EN 13445

The design of tanks are covered by:

API 620; API 650; BS 1564; BS 2594; BS 2654; BS 4741; BS 4994; BS 7777

The design of liquid pressurised systems are covered in:

ANSI B31; BS 806; BS 8010

Care should be exercised when considering system steady-state pressures and the possibility of fatigue through cycling. The requirements of pressure relieving valves and systems are dealt with in:

ANSI N278.1; API RP520; API RP521; API 526; API 527; API 2000; ASME PTC 25.3; BS 2915; BS 6283; BS 6759; ISO 4126; ISO 6718

The construction and dimensions of pipe fittings are standardised in:

ISO 49; ISO/R508; ISO 2045; ISO 2531; ISO 3458; ISO 3459; ISO 3501; ISO 3503; ISO 4145; ISO 4179; ISO 8179; BS 143; BS 759; BS 1256; BS 1640; BS 1740; BS 1965; BS 2051; BS 3799; BS 4346; BS 4772; BS 5114

A variety of standards deal with material specifications for pressure retaining parts.

Pressure vessels: ISO 2604; ISO 9328; EN 10028; EN 13445; ASME VIII; BS 5500.

Pipework: ISO 2604; ASME VIII.

A draft document issued by BSI, BS Draft DD 38, now withdrawn still includes useful information on pump materials. To ensure that a system is capable of withstanding the required nominal pressure it is necessary to pressure test all the equipment which is subjected to internal pressure. The standards dealing with pressure vessels contain regulations concerning pressure testing. For normal land use the pump must normally be tested to a pressure which is at least 30% greater than that of the specified nominal pressure. For marine pump systems regulations are laid down by the classification societies which often demand a greater margin of safety.

The risk of explosion is an important consideration from the point of view of safety. In Europe, there are special regulations for mechanical equipment.

EN 13463 Non-electrical equipment for potentially explosive atmospheres:

Part 1: Basic methodology and requirements.

Part 2: Protection by flow restricting enclosure 'fr'.

Part 3: Protection by flameproof enclosure.

Part 4: Protection by inherent safety.

Part 5: Protection by constructional safety.

Part 6: Protection by control of ignition sources.

Part 7: Protection by pressurisation.

Part 8: Protection by liquid immersion.

There are many standards covering the safety of electrical equipment and these standards contain a wealth of useful information for the mechanical and process engineers designing, selecting and arranging equipment. The following should be reviewed;

IEC 34-1; IEC 34-5; EN 60034 Part 5; BS 5345 and some sections of BS 4999.

The transmission of power between the motor and the pump presents another safety hazard. ANSI B15.1, BS 5304 and EN 953 are examples of the standards which contain criteria for the design, construction and application of guards for shaft couplings and other mechanical hazards. See also API RP 11ER.

For marine installations the instructions laid down by the classification societies, Lloyds Register for example, must be followed. The safety requirements being of particular importance, since a ship at sea cannot assume that assistance will be available in the event of an accident. It thus follows that the safety regulations on board ship are often much more stringent than

those of an equivalent installation for land use. In principle all equipment must be type-approved and also have passed special safety inspection controls before installation on board ship is permitted. Similar restrictions are imposed for equipment to operate on offshore platforms.

17.1.5 Reliability and operational life

The concepts of reliability and operational life have come more to the forefront in recent years as the demands for operational reliability and economy increase. Emphasis has been placed on total life-cycle costs rather than initial capital costs. This trend has been followed up by the organisations responsible for issuing standards and resulted in the development of instructions relating to pump design in order to fulfil these demands.

The API 610 specification concerning centrifugal pump reliability gives instructions and recommendations regarding the pump components which are associated with safety. Also dealt with are the factors which must be considered in a pump installation together with comments concerning the components such as shaft couplings and electric motors. The API specification applies primarily to the petroleum industry but is also applicable in other areas.

It is intended that this Standard becomes an accepted international guideline in respect to pump design for, among other things, reliability in operation. As mentioned earlier, inspectors cannot look at pumps and say "this one will only last two years but that one will last three".

Specifications applying to the design, construction, performance, reliability and testing of small-bore domestic heating and hot water pumps are also to be found in EN 60335-2-42; EN 60335-2-51; BS 1394; BS 3456 Part 202 Section 202.41.

The European Standard for reciprocating positive reciprocating pumps, EN 16330, includes NPIP margins and guidance on acceptable residual pulsation levels.

A curious twist occurred in the nature of pump specifications a few years ago. The major European oil companies realised that if they told the pump manufacturer how to build a pump for extended reliability and the pump was not reliable they would have no claim on the manufacturer. A group of oil companies discussed with certain manufacturers the possibility of purchasing pumps without specifications. The user would completely specify the duty and the time between overhauls. The pump manufacturer would supply a suitable pump. If the pump did not perform satisfactorily the manufacturer would cure the problems.

Before this plan could be widely implemented it was modified. The users decided it would be better if the pump manufacturer completed the complicated parts of the duty definition because the manufacturer knew what sort of things would cause problems in a pump for the specific duty.

This created two unexpected problems. The pump specialists at the consultants/contractors became surplus to requirements. The pump manufacturers could sell exotic pumps when "plain vanilla" would do. This utopian state of affairs did not last long and everything went back to normal!

17.1.6 Dimensions and performance

The advantages of standardised dimensions for individual components has long been recognised. The scope of standardisation has been developed to cover all aspects of machine design and construction. Since size and performance are often related to each other, it has proved practical to develop standards which have regard to these two parameters.

An example of this is ISO 2858 which specifies the principle dimensions and nominal duty points of horizontal end-section back-pull-out centrifugal pumps for pressure rating PN 16 (16 bar), mainly intended for chemical applications. The British version of this Standard is BS 5257 and the German is DIN 24256.

The European Standard for these pumps is EN 22858. Water pumps of the same type but rated at pressure class PN 10 are covered by the German Standard DIN 24255 and for Europe, EN 733. This Standard covers pumps of approximately the same size as ISO 2858 (BS 5257; EN 22858) but with reduced dimensions and higher port velocities.

BS 5257 also specifies dimensions for baseplate installations, ISO 3661, and seal cavities, ISO 3069. EN 60335-2-42; EN 60335-2-51; BS 1394 and BS 3456 Part 202 Section 202.41 cover the requirements for circulators for domestic heating and hot water installations for glandless pumps up to 300 W. The ISO 2858 Standard pump has not been accepted in the USA because of its metric dimensions. There is however an equivalent inch Standard, ANSI B73.1 which specifies dimensions and duty ratings in American units. ANSI B73.2 covers a range of inline vertical chemical pumps. BS 4082 specifies external dimensions, pressure-temperature ratings and nominal duty points at various speeds for vertical inline centrifugal water pumps. These apply to maximum differential heads of 160 m and maximum flows of 384 m³/h. EN 734 specifies the designations, dimensions and duty points of a range of multi-stage segmental pumps rated at PN 40. BS 7117 deals with construction, installation and maintenance of metering pumps specifically for dispensing liquid fuel.

ISO 13709/API 610 is a specification of pump construction and packaging together with materials and inspection requirements. Seal cavities, clearances and seal selection requirements are specified in EN ISO 21049/API 682. Hydraulic duties are not specified but test tolerances for water are given. 21049/610 allows performance testing on water up to 66 °C which gives good results based on vapour pressure rather than gas evolution.

ISO 13710/API 674, API 675 and API 676 cover positive displacement pumps; reciprocating, dosing and rotary. VDMA 24286 covers procurement, testing, supply and dispatch of the three positive displacement pump types. DIN 5437 covers semi-rotary hand pumps. DIN 24289 covers specification, installation and data sheets for reciprocating pumps.

17.1.7 Vibration and noise

Vibration and noise Vibration occurs in all rotating and reciprocating machinery when in operation. Vibrations are normally caused by imbalance of the rotating or reciprocating components, but can also be caused by hydraulic flow through a pump or valve. Since imbalance gives rise to vibration it is obviously desirable to maintain sufficiently low values so as to prevent mechanical damage. Noise is also created and is also undesirable from an environmental point of view. Standards and guidelines are available which specify maximum levels of vibration to avoid mechanical damage, loss of reliability and also to prevent unacceptably high noise levels. The standards dealing with noise and vibration are therefore basically concerned with the evaluation of maximum permissible vibration levels for various types of machinery and the requirements and specification of the necessary measuring equipment. Vibration levels are today measured as vibration velocity mm/s RMS instead of amplitude and frequency. This simplifies measurement and the evaluation of vibration levels.

The requirements for sensors and measuring equipment for vibration velocities in mm/s RMS within the frequency 10 to 1000 Hz are dealt with in ISO 2954, BS 4675: Part 2: 1978. ISO 3945 specifies how to measure and evaluate vibration at site for machines with speeds between 10 rev/s and 200 rev/s. ISO 8821 and BS 7130 specify the convention to be adopted regarding shaft keys. ISO 10816 Part 1, Part 3, Part 5 and Part 6 may be useful for vibration measurement of rotating and reciprocating

equipment when using sensors attached to bearing housings. The evaluation and recommendation of preferred vibration se-

verity ranges is complicated by the variations in design, construction and installation of different types of machinery. The VDI 2056; ISO 2372 and BS 4675: Part 1: 1976 have therefore divided up machines into groups. Rotodynamic pumps usually appear in group T (VDI) or Class IV (ISO and BSI), although some types may appear in other classification groups as a result of variations in design and construction. The pump manufacturer usually establishes the group to which a particular pump construction belongs.

The vibration level measured on a pump during testing is greatly influenced by the pump mounting. Temporary mounts on test rigs can be quite flexible allowing the pump to register high levels. Positive displacement pumps, both rotary and reciprocating, can suffer from vibration due to imbalance which cannot be rectified due to the pump design. Vibration readings during tests can only be used as information if the pump is mounted on temporary stands. When installed at site, and grouted in, the vibration levels will be much reduced.

IEC 994 and EN 60994 give guidance on vibration and pulsation measurement at site for rotodynamic pumps and turbines.

Other standards which may be useful include ISO 5343; ANSI S2.17; ANSI S2.40; API 678. Noise emitted by machinery constitutes a considerable problem where it is necessary for personnel to be present in the vicinity of machinery for long periods. Consideration must be given to the complete pump package not just the pump. The driver, plus any power transmission equipment, and process pipework will contribute to the overall noise level. Specific areas can be designated "ear protection zones" where ear defenders must be worn. Typical noise level restrictions in current specifications call for 84 dB(A).

EN 12639 is the European noise test code for pumps and pump units. This Standard has two grades of accuracy. Other current standards deal with the measurement, evaluation and presentation of noise data. The following Standards should be reviewed for suitability for any specific application: ISO 3740; EN ISO 3743-1; EN ISO 3743-2; EN ISO 3744; ISO 3745; EN ISO 3746; ISO 3747; ISO 4412; EN ISO 4871; ISO 6081/2; ISO TR 7849; EN ISO 9614-1; EN ISO 9614-2; EN ISO 11203; ISO 11689; EN 27574; ANSI B93.71; ANSI B93.72; ANSI S1.4; ANSI S1.4a; ANSI S1.6; ANSI S1.13; API 615; BS 4196; BS 7025 and DIN 45635. As most pumps are driven by electric motors the following Standards on noise from electric motors should be given consideration; ISO /R 1680, IEC 34-9 and BS 4999 Part 109.

17.1.8 Forces and moments on connections

Pump installations should be laid out so that the loads transmitted from the piping system to the pump connections are as small as possible. Considerable forces are brought to bear on the pump connections as a result of liquid pressure and thermal expansion, for example. A knowledge of the extent to which the pump connections are capable of withstanding forces and moments without risk is therefore important, from the point of view of pump installation and construction, so as to avoid the unnecessary use of compensating devices etc. However, the pump should not be looked upon as a pipe support or anchor. These are secondary functions for a pump and can be detrimental to the primary function. Instructions regarding the permissible forces and moments for centrifugal pumps are given in ISO 13709/API 610. This Standard determines the permitted forces and moments on the basis of the size of the flange connection and, to some extent, the weight of the pump. 13709/610 pumps are robust. Special reinforced baseplates are used because the nozzle load requirements are so high.

Other Standards use the maximum pump pressure and connection dimensions as the basis for determining the permitted forces and moments. The situation is further complicated by the

fact that different manufacturers employ their own individual methods of determining the permitted forces and moments. It is therefore advisable to contact the manufacturer for advice in cases of doubt.

EN ISO 14847 for rotary positive displacement pumps includes forces and moments data. DIN 24289-1 and EN ISO 16330 for reciprocating pumps includes forces and moment data. French National Standards, AFNOR, have standards NFE44-145 and NFE44-146, for forces and moments on horizontal and vertical centrifugal pump flanges.

17.1.9 Components

Many pump components and parts are not exclusively used on pumps, but are also used in many other types of machinery. The dimensions of such parts are usually the subject of separate component standards. Screws, plugs, keys and key ways for example, are basic pump components for which dimensional standardisation is a well known concept. The standards applying to certain other pump components, however, are worth studying more carefully.

Standard	Dimensions
ISO 7005	both
BS 4504	metric
DIN 2531 to 2533	metric
DIN 2543 to 2549 + 2551	metric
DIN 2628 + 2631 to 2638	metric
DIN 2565 to 2569	metric
ANSI B16.5 / BS 1560	inch
SAE	inch

Table 17.3 Popular flange standards

The shape and dimensions of flanges is dealt with by many standards which are subdivided according to material, type and pressure rating. The Standards in Table 17.3 are the most popular and cover working pressures up to 420 barg depending upon the material and the temperature.

Shaft end dimensions are given in ISO 775 and its equivalent BS 4506. These standards give specifications relating to various types of cylindrical and conical shaft ends with optional screw threads for retaining purposes.

Shaft centre heights and tolerances for driving and driven machines are standardised in ISO 496 and BS 5186. These standards should be read in conjunction with IEC 72 and IEC 72A which define shaft heights for electric motors. Mounting flanges, together with shaft sizes for hydraulic pumps and motors are covered by ISO 3091/1, ISO 3091/3, ANSI B93.81, BS 6276 and SAE J896.

Shaft seals are important machine elements in all pumps from a reliability point of view. Since there are many different types of seals manufactured by a great number of manufacturers, there has long been a necessity to establish some form of standardisation. DIN 3780 covers stuffing box dimensions for soft packing. DIN 24960 is a recent Standard and is derived from an earlier VDMA Standard for mechanical seal cavities and material codes. For further information see Chapter 8, Section 8.3.2.

The international Standard ISO 3069 and sections of its BSI equivalent, BS 5257, include tolerance and surface finish requirements for shafts and cavities also refer to shaft seals.

These standards only deal with the dimensioning of the actual sealing cavity. The manufacturer should be consulted about pressure/temperature/speed limitations. EN ISO 21049/API 682 and ANSI B73.1 and B73.2 all specify seal cavity dimensions.

EN ISO 21049/API 682 are major standards covering all aspects of mechanical seals. These standards deal with problems

associated with more stringent leakage and safety requirements including selection and testing.

There are no established dimensional standards for shaft couplings. Data concerning different types of shaft couplings are dealt with in Chapter 9. Some criteria concerning shaft couplings are covered by BS 3170 and API 671.

The Hydraulic Institute has issued a draft standard for baseplates for horizontal centrifugal pumps. Also a finalised standard for pump intake design.

17.1.10 Performance testing

Mass-produced pumps are subject to selective testing. Some manufacturers test all the rotating assemblies in fixed test casings; this is not a good policy and should be avoided. Pumps built specifically for contract will be tested when complete. The running test is the final check that the pump fulfils the agreed or specified requirements and is therefore of great importance to both the purchaser and the supplier.

Tests which closely resemble site conditions provide more confidence than tests of a general nature. Acceptance testing is usually carried out at the pump manufacturer's premises. The test facilities of pump manufacturers vary greatly and it is worthwhile evaluating the test procedures carefully before placing an order. It is obviously impracticable for the purchaser to fully specify the manner in which the acceptance test is to be carried out and evaluated for every order. Reference is normally made, therefore, to an acceptance testing standard which contains instructions regarding the testing procedure, permissible tolerances etc.

Testing standards and specifications have been issued by many standard issuing organisations, as shown by the list in Table 17.4. Some documents listed only specify acceptance tolerances. Documents which provide detailed instructions on test rigs and test methods are shown in **bold** type.

Pumps (all types)	EN 12162 (hydrostatic testing)*
Pump units (all types)	EN 12483 (pump units with variable frequency inverters)
Centrifugal pumps	API 610, DIN 1944 , HI 1.6
Circulators	EN 1151
Dosing & metering pumps	API 675
Effluent pumps	DIN 19760
Fire pumps	DIN 14420 , EN 1028-2
Fire pumps (portable)	DIN 14410
Hydraulic pumps and motors	ANSI B93.95 , BS 4617 , BS 7250 , ISO 4409 , ISO 8278 , ISO 8426
Positive displacement pumps	VDMA 24284
Pressure ripples in hydraulic systems	BS 6335
Reciprocating pumps	API 674, HI 6.6 (no EN or ISO)
Rotary positive displacement pumps	API 676, EN 14343
Rotodynamic pumps	ASME PTC 7 , 7.1, 8.2, 18.1, BS 5316-1 , BS 5316-2 , BS 5316-3 , EN ISO 5198 , ISO 2548 , ISO 3555 , ISO 5198 , ISO 9906
Rotodynamic pump/turbines (very large)	BS 5860 , EN 60041 , IEC 60041 , IEC 60607
Submersible pumps	API RP 11S2
Wells (flow testing with pumps)	BS 6316

* Methods of hydrostatic testing which impart external strength or stiffness to components should not be acceptable.

Table 17.4 Testing standards

EN 14343:2005 is the new Standard for performance tests for acceptance of rotary positive displacement pumps.

It is important to select a test standard which is compatible with the pump application to be tested. If a centrifugal pump is being

used to pump oil at 300 cSt it would be a good idea to test with a liquid which approaches the viscosity. Most rotodynamic pump test specifications call for "clean cold water". EN ISO 21049/API 610 allows performance testing on water up to 66 °C which gives good results based on vapour pressure rather than gas evolution. Some of the positive displacement pump test requirements do not specify anything about the liquid.

Some pump manufacturers are reluctant to test pumps on anything but water because of the inconvenience of organising a suitable liquid supply and cleaning the tanks afterwards. It may be possible to "borrow" a liquid like heating oil and use the tanker as a supply vessel. Some creative thinking may produce positive results. Users should not be thwarted by the first offer from the first manufacturer, but shop around.

BS 5316: Part 1 is a direct equivalent of ISO 2548, which, since its introduction, has become the dominating international standard for rotodynamic pumps for industrial applications. Petrochemical pumps are tested to EN ISO 21049/API 610 or the Hydraulic Institute. In all testing standards it is of course the maximum permissible tolerances of flow, differential head and efficiency which are of greatest interest. Some purchasers annex the testing standard to the purchaser order and add overriding clauses for the tolerances.

The correct choice of testing standard, when ordering and specifying, is obviously very important. The acceptance test standards for mass-produced pumps according to BS 5316 Part 1, can be about 10% higher than the specified duty point. The standards must be reviewed carefully to ensure the particular problems of a specific application are addressed.

Manufacturers should be assessed regarding their in-house process control systems. Great store is set by ISO 9000, EN 29000 and BS 5750. These Standards specify rules regarding how departments should work, how departments should communicate with each other and most important, what to do when things go wrong. Pumps for critical applications; nuclear, pharmaceutical, offshore; are normally purchased from manufacturers who operate one of the standard systems and have been vetted by an accredited third party assessor. All pump manufacturers should operate some type of formalised control system.

A traditional system can be as good as ISO, EN or BS when operated correctly and Quality Control staff are empowered to scrap substandard components. Enquiries for important pumps should always request a Vendor Document Requirement form, VDR, and a Quality Control Plan, QC Plan, to be submitted as part of the quotation. The VDR will show the purchaser what documentation; drawings, manuals, certificates; the manufacturer considers important and will supply with the pump. The QC Plan will show all the inspection operations, hold points and any conditions when Engineering must be contacted to exert overall control for important decisions. After carefully studying the VDR and the QC Plan, the true character of the manufacturer will be revealed.

BS 7929:1999 Guide for the verification of a pump casing design procedure, is useful when comparing pressure ratings and design methods for competitive pumps.

17.1.11 Hygiene

Much work has been carried out on the correct design and installation of pumps to be used on "liquids" which must not be contaminated. Two different areas of application are being addressed; foodstuffs for human or animal consumption and biotechnology.

The European committee considering foodstuffs applications has introduced a new term "agrifoodstuffs" to encompass both human and animal food applications. The new Standard EN 13951 includes provisions for design, surface finish, the choice of materials and verification of cleanability. Biotechnology re-

fers to processes which involve micro-organisms which may be hazardous.

Pump standards for biotechnology applications are at an early stage. EN 12690 provides seal selection guidelines for biotechnology processes. EN 12298 covers testing for pump leak resistance. Some guidance on hygienic requirements can be found in EN 1672-1 and 1672-2, Food processing machinery - Safety and hygiene requirements.

Additional guidance can be obtained from the European Hygienic Engineering & Design Group (EHEDG) who develops test methods to verify the suitability of equipment. Also, review ISO 14159 Safety of machinery - Hygiene requirements for the design of machinery. Care must be exercised as the ISO Standard may not conform precisely to European requirements.

EN 285, 12296 and 12297 provide guidance on steam sterilisation.

There is no European Standard for equipment suitable for drinking water, local national standards apply. The American NAFEM (North American Association of Food Equipment Manufacturers) should also be consulted.

17.1.12 Electromagnetic pollution

Over the years there has been a dramatic increase in the interference problems created by electrical and electronic equipment. Problems are being experienced with interference transmitted by the electric supply or distribution system and airborne electromagnetic waves. These are caused by the increased use of fluorescent lights, electronic control of incandescent lamps, computers, PLCs, variable frequency drive systems and mobile telephones.

Many standards have been introduced to try to ensure that electric/electronic equipment will work in harmony. Most pumps are driven by electric motors and the pump unit must conform to the electromagnetic pollution requirements.

EN 61000-2 Electromagnetic compatibility (EMC); Part 2: Environment;

Section 2: Compatibility levels for low frequency conducted disturbances and signalling in public low-voltage power supply systems (similar to IEC 1000-2-2) 'CE'.

Section 4: Compatibility levels in industrial plants for low frequency conducted disturbances (IEC 1000-2-4) 'CE'.

EN 61000-3 Electromagnetic compatibility (EMC); Part 3: Limits.

Section 2: Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)(IEC 1000-3-2) 'CE'.

Section 3: Limitation of voltage fluctuations and flicker in low-voltage supply systems for equipment with rated current ≤ 16 A (IEC 1000-3-3) 'CE'.

EN 61000-4-1 Electromagnetic compatibility (EMC); Part 4: Testing and measuring techniques:

Section 1: Overview of immunity test; Basic EMC publication (IEC 1000-4-1) 'CE'.

Section 2: Electrostatic discharge immunity test; Basic EMC publication (IEC 1000-4-2) 'CE'.

Section 4: Electrical fast transient/burst immunity test; Basic EMC publication (IEC 1000-4-4) 'CE'.

Section 5: Surge immunity test (IEC 1000-4-5) 'CE'.

Section 7: General guide on harmonics and interharmonic measurement and instrumentation for power supply systems and equipment connected thereto (IEC 1000-4-7) 'CE'.

Section 8: Power frequency magnetic field immunity test; Basic EMC publication (IEC 1000-4-8) 'CE'.

Section 9: Pulse magnetic field immunity test; Basic EMC publication (IEC 1000-4-9) 'CE'.

Section 10: Damped oscillatory magnetic field immunity test; Basic EMC publication (IEC 1000-4-10) 'CE'.

Section 11: Voltage dips, short interruptions and voltage variations immunity tests (IEC 1000-4-11) 'CE'.

Section 12: Oscillatory waves immunity tests - Basic EMC publication (IEC 1000-4-12) 'CE'.

17.2 SI, The International System of Units

Système International d'Unités, (international abbreviation, SI) the international measurement unit system is based on an earlier metric system and is being used more extensively worldwide. The SI system is systematically constructed to cover in practice all scientific, technical and daily requirements and is subject to international agreement. This means that it is now possible to apply the SI system uniformly throughout the world. A measurement system which is suitable for all technical and scientific purposes has to fulfil many requirements. Some of the basic requirements which SI satisfies are consistency, consequential applicability, coherence, the convenient expression of multiples and sub-multiples over a wide range of numerical values and accuracy.

- Consistency means that each unit shall represent one, and only one, quantity.
- Consequential applicability means that each quantity shall be measured in one, and only one, unit.
- Coherence means that all units for every quantity shall be compatible so as to eliminate the need for arbitrary conversion factors in calculations involving related quantities.
- Convenient expression of multiples and sub-multiples means the convenient multiplication of units to enable the use of practical numerical values within a particular application.
- Accuracy means that the base units shall be precisely derived and defined. Six of the seven base units are thus determined from distinct precisely defined physical phenomena, the seventh, the kilogram, is determined by one standard body which is held in Paris.

In 1971 the EEC, now the EC (European Community) ratified a Directive, 71/354/EEC, on units which committed all member states to amend legislation to authorise SI units within 18 months of that date and to implement all provisions of the Directive within a further five years. An amending Directive, 76/770/EEC, legislates the obligations. The Units of Measurement Directives place non-SI units into four chapters A to D.

Chapter A prescribes those units which are for permanent use and member states are obliged to authorise them in their laws by 21 April, 1978.

Chapter B contains a list of all units which member states have undertaken to cease to authorise in their laws with effect from 31 December, 1977.

Chapter C contains a list of units which member states have undertaken to cease to authorise in their laws with effect from 31 December, 1979.

Chapter D covers remaining units and some other units and will be reviewed before 31 December, 1979.

The formal content of the SI is determined and authorised by the General Conference of Weights and Measures (CGPM) and, for more detailed descriptions of the System reference should be made to BS 3763 and SI - The International System of Units published by the UK Office of Public Sector Information

(formerly called HMSO). However, the basic advice to industry on the use of SI is now contained in ISO 1000, BS 5555.

The SI system includes two classes of units:

- Base units
- Derived units

The system also includes a number of Non-SI units, the "bar" for example, which are retained for use together with the SI units and their multiples because of their practical importance or because of their specialized fields. Multiples and sub-multiples of SI units and recognised Non-SI units are formed by attaching a prefix, micro, milli, kilo, Mega etc., to the unit symbol.

17.2.1 Brief history of unit systems

Although often called the metric system, the SI system essentially has more basic units and overcomes problems encountered during the development of a consistent system of units to serve all science and engineering functions. The metric system was introduced at the beginning of the nineteenth century based on the unit of length being the metre. The unit of mass followed and together with the unit of time formed the basic metric system. In 1873 the British Association for the Advancement of Science agreed on the use of the centimetre, gramme and second as the basic units for scientific work (the CGS system) but engineering within the United Kingdom had been well established using the British units of feet, pounds and seconds (the FPS system). As electrical experiments took place it was the metric system that became the basis for units peculiar to the electrical sciences and many basic electrical units were added to the CGS system.

An international authority on the metric system was established in 1875 with the Bureaux International des Poids et Mesures at Sèvres defining the units of length, mass and time as the metre, kilogramme and second respectively (the MKS system) as these units were more convenient than the CGS system. The basic units of length, mass and time are insufficient to cover electrical units and consequently units employing the permeability and permittivity of free space became necessary. Confusion also arose because of the links with the CGS system with, in particular, the use of p (the ratio of the circumference of a circle to its diameter) appearing in equations which were usually not associated with circles.

To overcome the complications the International Electrotechnical Commission (IEC) rationalized the units in 1950 and adopted as a fourth basic unit the unit of electrical current, the ampere (the MKSA system). This had been suggested about a half century earlier by an Italian professor called Giorgi and this system of units was consequently named the Giorgi System. Although this system of units covered electrical engineering it did not cover all branches of science and consequently the Conférence Générale des Poids et Mesures (CGPM) in 1954 agreed a rationalized and coherent system of units which became in 1960 the SI system.

After some subsequent additions the system now has seven basic units as follows:

length	metre (m)
mass	kilogramme (kg)
time	second (s)
electric current	Ampere (A)
light	candela (cd)
temperature	Kelvin (K)
substance	mole (mol)

In addition the following supplementary units are in use:

plane angle	radian (rad)
solid angle	steradian (sr)

The supplementary units are both ratios and therefore have no basic units.

The SI system is based around the seven basic units and the two supplementary units together with derived units for the more commonly used quantities and a series of prefixes used for the formation of multiples and submultiples.

Actual temperatures are normally expressed in Celsius units ($^{\circ}\text{C}$) and temperature differences in Kelvin units (K).

17.2.2 Method of expressing symbols and numbers

The following rules apply to symbols for units

- The symbol should be lower case unless the unit is derived from a proper name in which case the symbol should be upper case (or the first letter upper case if more than one letter), for example, metre - m, Ampere - A, Hertz - Hz
- The symbol should not contain a final full stop, for example, m not m.
- The symbol should remain unaltered in the plural, for example, m not ms
- If multiple symbols are required they should be separated by a space if confusion can occur, for example, kg m/s^2 not kgm/s^2 . If a pair of units are each represented by a single letter they are not separated if the absence of a space is not likely to cause confusion, for example Nm
- The symbol should be reduced to its simplest expression, for example, W not J/s, Js^{-1} , $\text{kg m}^2/\text{s}^3$ or $\text{kg m}^2 \text{s}^{-3}$
- Where more than one symbol is required and division is involved use a solidus or superscript, do not use more than one solidus, for example, use m/s^2 or m s^{-2} , do not use m/s/s

Large numbers should be written with the digits grouped in threes and with a '.' or ',' used to denote the decimal place, for example, 12 345 678, 0.000 012, 0.012 3. Use 10 000 not 10,000 to denote ten thousand, for example. One exception to this rule is that numbers with only four digits and without a decimal point do not normally have the space after the first digit, for example 1234 not 1 234.

Alternatively very large or very small numbers can be represented in exponential form, that is a number multiplied by a factor in the form of 10 to a positive or negative power. For example 100 is equivalent to 10^2 and 0.001 is equivalent to 10^{-3} . Therefore 1 234 000 can be expressed in the form 1.234×10^6 and 0.0123 can be expressed as 1.23×10^{-2} .

There is a further group of specialised units which are primarily for use within astronomy and physics.

17.2.3 Multiples of SI units

The prefixes in Table 17.5 are used to form names and symbols of multiples and subdivisions of the SI units. The symbol of a prefix is considered to be combined with the unit symbol for the base unit, supplementary unit or derived unit to which it is directly attached, forming with it a symbol for a new unit which can be provided with a positive or negative exponent and which can be combined with other unit symbols to form symbols for compound units.

Factor by which the unit is multiplied	Prefix		Example
	name	symbol	
10^{24}	yotta	Y	
10^{21}	zetta	Z	
10^{18}	exa	E	
10^{15}	peta	P	
10^{12}	tera	T	1 terrajoule = 1TJ
10^9	giga	G	1 gigawatt = 1GM

Factor by which the unit is multiplied	Prefix		Example
	name	symbol	
10 ⁶	mega	M	1 megavolt = 1 MV
10 ³	kilo	k	1 kilometre = 1 km
10 ²	hecto	h	1 hectogram = 1 hg
10 ¹	deca	da	1 decalumen = 1 dalm
10 ⁻¹	deci	d	1 decimetre = 1 dm
10 ⁻²	centi	c	1 centimetre = 1 cm
10 ⁻³	milli	m	1 milligram = 1 mg
10 ⁻⁶	micro	μ	1 microgram = 1 μm
10 ⁻⁹	nano	n	1 nanohenry = 1 nH
10 ⁻¹²	pico	p	1 picofarad = 1 pF
10 ⁻¹⁵	femto	f	1 femtometre = 1 fm
10 ⁻¹⁸	atto	a	1 attosecond = 1 as

Table 17.5 Multiples of SI units

Whenever possible units should be multiples or submultiples of 3 - hecto, deca, deci and centi therefore should not normally be used.

The prefix symbol should appear immediately before the basic symbol, for example mA for milliampere. It should be noted that mm³ means (0.001 m)³ not 0.001 m³ and that mm⁻¹ means (10⁻³ m)⁻¹ not 10⁻³ m⁻¹. The use of dk should be avoided as this may cause confusion, for example, dkg is decagramme not deci killogramme.

It is normal practice to use millimetre (mm) as the unit of length on engineering drawings.

17.2.4 Derived units

These are expressed in terms of base units and/or supplementary units by multiplication and division according to the laws of physics relating the various quantities, see Table 17.6.

Quantity	Name of derived SI unit	Symbol	Expressed in terms of base or supplementary units
frequency	Hertz	Hz	1 Hz = 1/s
force	Newton	N	1 N = 1 kg m/s ²
pressure, stress	Pascal	Pa	1 Pa = 1 N/m ²
energy, work, heat	Joule	J	1 J = 1 Nm
power	Watt	W	1 W = 1 J/s
electric charge, quantity of electricity	Coulomb	C	1 C = 1 A s
electric potential	Volt	V	1 V = 1 J/c = 1 W/A
electric capacitance	Farad	F	1 F = 1 C/V
electric resistance	Ohm	Ω	1 Ω = V/A
electric conductance	Siemens	S	1 S = 1/Ω
magnetic flux	Weber	Wb	1 Wb = 1 V s
magnetic flux density	Tesla	T	1 T = 1 Wb/m ²
inductance	Henry	H	1 H = 1 Wb/A
luminous flux	lumen	lm	1 lm = 1 cd sr
illuminance	lux	lx	1 lx = 1 lm/m ²
radioactivity	Becquerel	Bq	1 Bq = 1/s
absorbed dose	Gray	Gy	1 Gy = 1 J/kg

Table 17.6 Some derived SI units having special names

Non-SI units. There are certain units not included in SI which cannot, for a variety of reasons, be eliminated, despite the fact that these can, in principle, be expressed in SI units. Some of the non-SI units which may be used together with the SI units

and their multiples and are recognised by the CIPM, Comité International des Poids et Mesures, are shown in Table 17.7.

Quantity	Name of unit	Unit symbol	Definition
Time	minute	min	1 min = 60 sec
Time	hour	h	1 h = 60 min
Time	day	d	1 d = 24 h
Plane angle	degree	°	1° = (π/180) rad
Plane angle	minute	'	1' = (1/60)°
Plane angle	second	"	1" = (1/60')
Volume	litre	l	1 l = 1 dm ³
Mass	tonne	t	1 t = 10 ³ kg
Pressure of fluid	bar	bar	1 bar = 10 ⁵ Pa

Table 17.7 Non-SI units

Conductance is sometimes used as the reciprocal of resistance for which the unit is the Siemen (S), also referred to as mho.

17.3 Conversion factors for SI units

A number of electrical terms evolved from the CGS system may still be encountered as well as units in the FPS system and other special units. In general it is best to convert units to the SI system before inserting quantities into equations as this will avoid problems involving conversion factors in the equations themselves. The engineering units which may be encountered in other systems of units are listed in Tables 17.8 to 17.10 with the conversion factor to give SI units.

Quantity	Unit	Conversion factor	SI unit
Length	cable	219.456	m
	chain (Gunter's)	20.116 8	
	chain (Ramden's)	30.48	
	fathom	1.828 8	
	feet	0.304 8	
	furlong	201.168	
	inch	0.025 4	
	micron	1 x 10 ⁻⁶	
	mile (nautical Brit)	1.853 184 x 10 ³	
	mile (nautical Int)	1.852 x 10 ³	
	mile (statute)	1.609 34 x 10 ³	
	mil	2.54 x 10 ⁻⁵	
	rod	5.029 2	
	yard	0.914 4	
Area	acre	4.046 856 x 10 ³	m ²
	are	100	
	centare	1	
	hectare	1 x 10 ⁴	
Volume	barrel (Brit)	0.163 65	m ³
	barrel (US petrol)	0.158 98	
	barrel (US dry)	0.115 63	
	barrel (US liquid)	0.119 24	
	gallon (Brit) (Imp)	4.545 9 x 10 ⁻³	
	gallon (US dry)	4.404 8 x 10 ⁻³	
	gallon (US liquid)	3.785 3 x 10 ⁻³	
	litre	1 x 10 ⁻³	
	ounce (Brit fluid)	2.841 225 x 10 ⁻⁵	
	ounce (US fluid)	2.957 373 x 10 ⁻⁵	
	pint (Brit) (Imp)	5.682 4 x 10 ⁻⁴	
	pint (US dry)	5.505 95 x 10 ⁻⁴	
	pint (US liquid)	4.731 63 x 10 ⁻⁴	
	quart (Brit) (Imp)	1.136 49 x 10 ⁻³	
	quart (US dry)	1.101 19 x 10 ⁻³	
	quart (US liquid)	9.463 2 x 10 ⁻⁴	

Table 17.8 Conversion factors for length, area and volume

To obtain the quantity in SI units, the original units should be multiplied by the conversion factor, for example, to convert a length of 10 inch to metre units multiply by 0.0254 giving 0.254 m. To convert from one non-SI unit to another non-SI unit,

first convert to the SI unit by multiplying by the conversion factor and then convert to the other non-SI unit by dividing by the conversion factor for the other unit. If multiple units are involved, convert each separately by multiplying by the appropriate conversion factor for any units with positive powers and dividing by the appropriate conversion factors for any units with negative powers. For example, to convert lb/in^3 (or lb in^{-3}) to SI units multiply by 0.453 6 to convert lb to kg and divide by $0.025 4^3$ to convert in^{-3} to m^{-3} giving $27\,680\text{ kg m}^{-3}$ (or 27680kg/m^3).

To convert Fahrenheit to Celsius or centigrade subtract 32 and then multiply by 5/9.

To convert Fahrenheit to Rankine add 459.67

To convert Celsius and centigrade to Kelvin add 273.15

To convert Rankine to Kelvin multiply by 5/9

For temperature conversion to Kelvin (K) the following should be noted:

Absolute zero =	0 Kelvin
	0 Rankine
	-273.15 Celsius
	-273.15 centigrade
	-459.67 Fahrenheit
Ice point =	273.15 Kelvin
	491.67 Rankine
	0 Celsius
	0 centigrade
	32 Fahrenheit

Quantity	Unit	Conversion factor	SI unit
Energy and Work	British Thermal Unit (Btu)	$1.054\,35 \times 10^3$	J
	Btu (IST)	$1.055\,04 \times 10^3$	
	Btu (mean)	$1.055\,87 \times 10^3$	
	Btu (39°F)	$1.059\,66 \times 10^3$	
	Btu (60°F)	$1.054\,68 \times 10^3$	
	calorie, gm (cal, gm)	4.184	
	cal, gm (mean)	4.19	
	cal, gm (15°C)	4.186	
	cal, gm (20°C)	4.182	
	calorie, kg (cal, kg)	4.184×10^3	
	cal, kg (mean)	4.19×10^3	
	centigrade heat unit (15°C)	$1.898\,3 \times 10^3$	
	erg	1×10^{-7}	
	foot-pound	1.355 82	
Force	dyne	1×10^{-5}	N
	kilogramme force	9.807	
	poundal	0.138 255	
Mass	hundredweight (long)	50.802 3	kg
	hundredweight (short)	45.359 2	
	ounce (troy)	0.031 103	
	ounce (avdp)	0.028 35	
	pounds (troy)	0.373 241	
	pounds (avdp)	0.453 592	
	slugs	14.593 9	
	ton (long)	$1.106\,046 \times 10^3$	
	ton (short)	$9.071\,847 \times 10^2$	
	ton (metric) (tonne)	1×10^3	
Power	cheval-vapeur	735.499	W
	horsepower	746	
	horsepower (boiler)	$9.809\,5 \times 10^3$	
	horsepower (metric)	735.499	
Pressure	atmosphere (atm)	$1.103\,25 \times 10^5$	Pa
	bar	1×10^5	
	inch of mercury (32°F) (in Hg)	$3.386\,4 \times 10^3$	
	inch of mercury (60°F) (in Hg)	$3.376\,1 \times 10^3$	
	inch of water (4°C) (in H ₂ O)	0.248 7	
	mm of mercury (0°C)	133.313	
	torr	133.313	
Velocity	knot	0.514 4	m/s

Quantity	Unit	Conversion factor	SI unit
Viscosity (dynamic)	centipoise (cp)	1×10^{-3}	Ns/m ²
	poise (p)	0.1	
Viscosity (kinematic)	centistoke (cSt)	1×10^{-6}	m ² /s
	Stoke (St)	1×10^{-4}	

Table 17.9 Conversion factors for quantities related to mechanics

Quantity	Unit	Conversion factor	SI unit
Electric charge	Faraday (chem)	9.649×10^4	C
	Faraday (phys)	9.652×10^4	
Magnetic flux	line	1×10^{-8}	Wb
	Maxwell	1×10^{-8}	
Magnetic flux density	Gauss	1×10^{-4}	T
Magnetizing force	Oersted	79.577 47	A-turns/m
Magnetomotive force	Gilbert	0.795 77	A-turns

Table 17.10 Conversion factors for quantities

Detailed conversion information is now given for a number of different quantities.

17.3.1 Plane angle

Quantity designation: α , β , γ

SI unit: radian, rad.

Normal multiple units: mrad, μrad .

Example: $2\text{ rad} = 2 \times 57.2958 = 114.5916^\circ$

rad	... g gon, grade	... ° degree	... ' minute	... '' second	angular mil
1	63.6620	57.2958	3.43775×10^3	0.206265×10^6	1.00268×10^3
15.7080×10^{-3}	1	0.9	54	3.24×10^3	15.75
17.4533×10^{-3}	1.11111	1	60	3.6×10^3	17.5
0.290888×10^{-3}	18.5185×10^{-3}	16.6667×10^{-3}	1	60	0.291667
4.84814×10^{-6}	0.308642×10^{-3}	0.277778×10^{-3}	16.6667×10^{-3}	1	4.86111×10^{-3}
0.997331×10^{-3}	63.4921×10^{-3}	57.1429×10^{-3}	3.42857	205.714	1

grade (g) (or gon), $1\text{ g} = 1\text{ gon} = \mu/200\text{ rad}$.

$1^\circ = \pi/180\text{ rad}$.

For some purposes, the angular mil is taken to be 10^{-3} rad . The figures shown here are based on the concept that an angular mil is equal to $360/6400$ degrees.

NOTE: 1 grade (... g) = 1/100 of a right angle

17.3.2 Length

Quantity designation l.

SI unit: metre (m).

Normal multiple units: km, cm, mm, μm .

Example: $3\text{ in} = 3 \times 25.4 \times 10^{-3} = 76.2 \times 10^{-3}\text{ m}$

metre m	inch in	foot ft	yard yd	mile
1	39.370	3.2808	1.0936	$0.62137 \cdot 10^{-3}$
$25.4 \cdot 10^{-3}$	1	$83.333 \cdot 10^{-3}$	$27.778 \cdot 10^{-3}$	$15.783 \cdot 10^{-6}$
0.3048	12	1	0.33333	$0.18939 \cdot 10^{-3}$
0.9144	36	3	1	$0.56818 \cdot 10^{-3}$
$1.6093 \cdot 10^3$	$63.36 \cdot 10^3$	$5.28 \cdot 10^3$	$1.76 \cdot 10^3$	1
$1.852 \cdot 10^3$	$72.913 \cdot 10^3$	$6.0761 \cdot 10^3$	$2.0254 \cdot 10^3$	1.1508

1 nautical mile = 6080 ft = 1853.184 m

1 Å, 1 Ångström = 10^{-10} m

1 astronomic unit = $0.1496 \cdot 10^{12}$ m

1 light year = $9.4605 \cdot 10^{15}$ m

1 parsec = $30.857 \cdot 10^{12}$ m

17.3.3 Area

Quantity designation: A.

SI unit: square metre (m²).

Normal multiple units: km², dm², cm², mm².

Example: 4 ft² = $4 \cdot 92.903 \cdot 10^{-3} = 0.371612$ m²

m ²	in ²	ft ²	yd ²	acre	square mile mile ²
1	$1.5500 \cdot 10^3$	10.764	1.1960	$0.24710 \cdot 10^{-3}$	$0.38610 \cdot 10^{-6}$
$0.64516 \cdot 10^{-3}$	1	$6.9444 \cdot 10^{-3}$	$0.77161 \cdot 10^{-3}$	$0.15942 \cdot 10^{-6}$	$0.24910 \cdot 10^{-9}$
$92.903 \cdot 10^{-3}$	144	1	0.11111	$22.957 \cdot 10^{-6}$	$35\text{--}870 \cdot 10^{-9}$
0.83613	$1.296 \cdot 10^3$	9	1	$0.20661 \cdot 10^{-3}$	$0.32283 \cdot 10^{-6}$
$4.0469 \cdot 10^{-3}$	$6.2726 \cdot 10^6$	$43.56 \cdot 10^3$	$4.84 \cdot 10^3$	1	$1.5625 \cdot 10^{-3}$
$2.5900 \cdot 10^6$	$4.0145 \cdot 10^9$	$27.878 \cdot 10^6$	$3.0976 \cdot 10^6$	640	1

1 acre = 100 m²

1 hectare = 100 acres = 10000 m²

17.3.4 Volume

Quantity designation: V.

SI unit: cubic metre (m³).

Normal multiple units: dm³, cm³, mm³.

Non SI unit: litre (l): 1 l = 0.001 m³ = 1 dm³.

Normal multiple units: cl, ml.

Example:

5 US gallon = $5 \cdot 3.7854 \cdot 10^{-3} = 18.927 \cdot 10^{-3}$ m³ = 18.927 l

m ³	in ³	ft ³	yd ³	UK gallon	US gallon
1	$61.024 \cdot 10^3$	35.315	1.3080	219.97	264.17
$16.387 \cdot 10^{-6}$	1	$0.57870 \cdot 10^{-3}$	$21.434 \cdot 10^{-6}$	$3.6046 \cdot 10^{-3}$	$4.3290 \cdot 10^{-3}$
$28.317 \cdot 10^{-3}$	$1.728 \cdot 10^3$	1	$37.037 \cdot 10^{-3}$	6.2288	7.4805
0.76456	$46.656 \cdot 10^3$	27	1	168.18	201.97
$4.5461 \cdot 10^{-3}$	277.42	0.16054	$5.9461 \cdot 10^{-3}$	1	1.2010
$3.7854 \cdot 10^{-3}$	231	0.13368	$4.9511 \cdot 10^{-3}$	0.83268	1

gross (register) tonnage used in shipping

1 ton = 100 ft³ = 2.83168 m³

1 UK fluid ounce, fl oz = 28.4131 cm³

1 US fluid ounce, fl oz = 29.5735 cm³

17.3.5 Time

Quantity designation: t.

SI unit: second (s).

Normal multiple units: ms, s, ns.

Non SI units: day (d), hour (h), minute (min).

Example: 100000 s = 100000/3600 = 27.778 h

s	min	h	d (day)	week
1	$16.6667 \cdot 10^{-3}$	$0.277778 \cdot 10^{-3}$	$11.5741 \cdot 10^{-6}$	$1.65344 \cdot 10^{-6}$
60	1	$16.6667 \cdot 10^{-3}$	$0.694444 \cdot 10^{-3}$	$99.2063 \cdot 10^{-6}$
$3.6 \cdot 10^3$	60	1	$41.6667 \cdot 10^{-3}$	$5.95238 \cdot 10^{-3}$
$86.4 \cdot 10^3$	$1.44 \cdot 10^3$	24	1	0.142857
$604.8 \cdot 10^3$	$10.08 \cdot 10^3$	168	7	1

1 tropical year = 31556925.974 s = 365.24219878 d

1 sidereal year = 31558150 s

1 calendar year = 365 d = 8760 h

17.3.6 Linear velocity

Quantity designation: v.

SI unit: metre per second (m/s).

Normal multiple units: km/h.

m/s	km/h	ft/s	mile/h
1	3.6	3.2808	2.2369
0.27778	1	0.91134	0.62137
0.3048	1.0973	1	0.68182
0.44704	1.6093	1.4667	1
0.51444	1.852	1.6878	1.1508

1 knot = 1 nautical mile per hour = 1.853 km/h

17.3.7 Linear acceleration

Quantity designation: a.

SI unit: metre per second squared (m/s²).

m/s ²	cm/s ²	ft/s ²	in/s ²	g
1	100	3.2808	39.37	0.10197
10×10^{-3}	1	$32.808 \cdot 10^{-3}$	$393.7 \cdot 10^{-3}$	$1.0197 \cdot 10^{-3}$
0.3048	30.48	1	12	$31.081 \cdot 10^{-3}$
25.4×10^{-3}	2.54	$83.33 \cdot 10^{-3}$	1	$2.59 \cdot 10^{-3}$
9.80665	980.665	32.174	386.09	1

17.3.8 Angular velocity

Quantity designation:

SI unit: radian per second (rad/s).

The SI and Imperial units are identical.

Angular velocity is normally calculated from N revolutions/s by 2 N

17.3.9 Angular acceleration

Quantity designation: a.

SI unit: radian per second squared (rad/s^2)

The SI and Imperial units are identical.

17.3.10 Mass

Quantity designation: m.

SI unit: kilogram (kg).

Normal multiple units: g, mg.

Non SI unit: tonne (t) = 1000 kg.

kg	lb (pound)	oz (ounce)	hundred-weight cwt (UK)	ton (UK)
1	2.2046	35.274	$19.684 \cdot 10^{-3}$	$0.98421 \cdot 10^{-3}$
0.45359	1	16	$8.9286 \cdot 10^{-3}$	$0.44643 \cdot 10^{-3}$
14.594	32.174	514.79	$0.28727 \cdot 10^{-3}$	$14.363 \cdot 10^{-3}$
$28.350 \cdot 10^{-3}$	$62.5 \cdot 10^{-3}$	1	$0.55804 \cdot 10^{-3}$	$27.902 \cdot 10^{-6}$
50.802	112	$1.792 \cdot 10^3$	1	$50 \cdot 10^{-3}$
$1.0161 \cdot 10^3$	$2.24 \cdot 10^3$	$35.84 \cdot 10^{-3}$	20	1

oz = ounce, also called ounce avoirdupois

1 ounce troy = $31.1035 \cdot 10^{-3}$ kg

cwt = hundredweight

USA cwt = 100 lb USA ton = 2000 lb

17.3.11 Density

Also called specific weight.

Quantity designation: .

SI unit: kilogram per cubic metre (kg/m^3)

Non SI units: kg/dm^3 , g/cm^3 .

kg/m^3	g/cm^3	lb/in^3	lb/ft^3
1	10^{-3}	$36.127 \cdot 10^{-6}$	$62.428 \cdot 10^{-3}$
10^3	1	$36.127 \cdot 10^{-3}$	62.428
$27.680 \cdot 10^3$	27.680	1	$1.728 \cdot 10^3$
16.019	$16.019 \cdot 10^{-3}$	$0.57870 \cdot 10^{-3}$	1

The term specific gravity or relative density is also used and is the ratio of the mass of a given volume of substance to the mass of an equal volume of water at temperature of 4°C and a pressure of 101.325 kPa absolute. The density of water at 4°C and 101.325 kPa absolute is 1000.02 kg/m^3 .

17.3.12 Force

Quantity designation: F.

SI unit: newton (N).

Normal multiple units: MN, kN.

N	dyn	Kilogram-force, kgf kilopond,	pound-force lbf
1	$0.1 \cdot 10^6$	0.10197	0.22481
$10 \cdot 10^{-6}$	1	$1.0197 \cdot 10^{-6}$	$2.2841 \cdot 10^{-6}$
9.8066	$0.98066 \cdot 10^6$	1	2.2046
4.4482	$0.44482 \cdot 10^6$	0.45359	1

17.3.13 Torque

Quantity designation: T.

SI unit: Newton metre (Nm).

Normal multiple units: MNm, kNm.

Nm	kgf m	lbf × in	lbf × ft
1	0.10197	8.8508	0.73756
9.8066	1	86.796	7.2330
0.11299	$11.521 \cdot 10^{-3}$	1	$83.333 \cdot 10^{-3}$
1.3558	0.13826	12	1

Torque, power and speed are related by the formula: $P = 2 \text{ NT}$

17.3.14 Pressure, stress

Quantity designation: p, .

SI unit: Pascal (Pa), $1 \text{ Pa} = 1 \text{ N/m}^2$.

Normal multiple units: GPa, MPa, kPa and for stress: MN/m^2 , N/m^2 , N/mm^2 .

Pa	bar	kgf/cm ² technical atmos	kgf/mm ²	Torr (≈ mm Hg)	standard atm	lbf/in ² (psi)
1	$10 \cdot 10^{-6}$	$10.197 \cdot 10^{-6}$	$0.10197 \cdot 10^{-6}$	$7.5006 \cdot 10^{-3}$	$9.8692 \cdot 10^{-6}$	$0.14504 \cdot 10^{-3}$
$100 \cdot 10^3$	1	1.0197	$10.197 \cdot 10^{-3}$	750.06	0.98692	14.504
$98.066 \cdot 10^3$	0.98066	1	$10 \cdot 10^{-3}$	735.56	0.96784	14.223
$9.8066 \cdot 10^6$	98.066	100	1	$73.556 \cdot 10^3$	96.784	$1.4223 \cdot 10^3$
133.32	$1.3332 \cdot 10^{-3}$	$1.3595 \cdot 10^{-3}$	$13.595 \cdot 10^{-6}$	1	$1.3158 \cdot 10^{-3}$	$19.337 \cdot 10^{-3}$
$101.32 \cdot 10^3$	1.0132	1.0332	$10.332 \cdot 10^{-3}$	760	1	14.696
$6.8948 \cdot 10^3$	$68.948 \cdot 10^{-3}$	$70.307 \cdot 10^{-3}$	$0.70307 \cdot 10^{-3}$	51.715	$68.046 \cdot 10^{-3}$	1

The preferred pressure unit for pump applications is the "bar".

1 mm H₂O 9.81 Pa

1 in H₂O 249.09 Pa

1 in Hg 3386.4 Pa

1 ata = 1 technical atmosphere (absolute)

1 atu = 1 technical atmosphere (gauge)

17.3.15 Dynamic viscosity

Quantity designation: .

SI unit: Pascal second Pa s.

Normal multiple units mPa s (= cP).

N s/m ²	N s/mm ²	P (poise)	cP m Pa s
1	10^{-6}	10	10^3
10^6	1	10×10^6	10^9
0.1	0.1×10^{-6}	1	100
10^{-3}	10^{-9}	10×10^{-3}	1

17.3.16 Kinematic viscosity

Quantity designation: .

SI unit: square metres per second (m^2/s).

Normal multiple units: mm^2/s .

For conversion to other units of viscosity see nomogram in Figure 17.1.

m^2/s	mm^2/s cSt	St (Stoke)
1	10^6	$10 \cdot 10^3$
10^{-6}	1	$10 \cdot 10^{-3}$
$0.1 \cdot 10^{-3}$	100	1

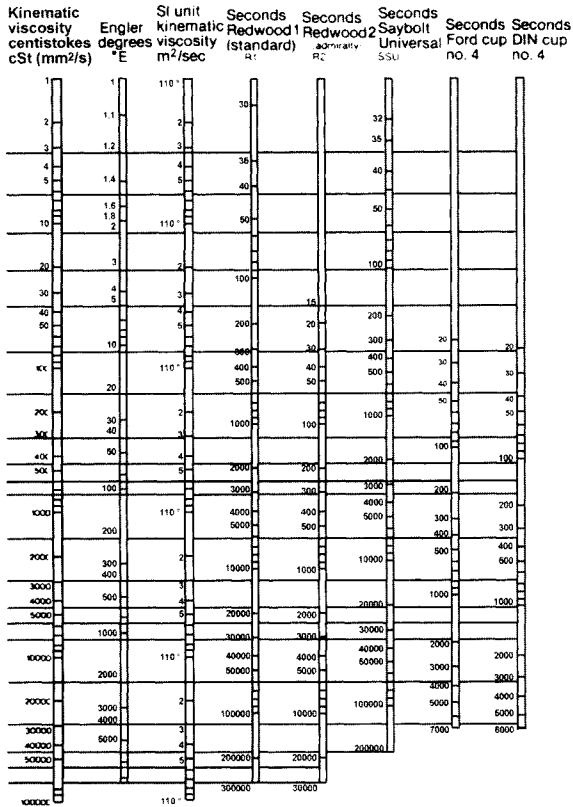


Figure 17.1 Nomogram for conversion of Kinematic viscosity to other units of viscosity, in Section 17.316

	cSt x	°E x	R1 x	SSU x
Kinematic viscosity cSt	1	7.58	0.247	0.216
Engler degrees °E	0.132	1	0.0326	0.0285
Seconds, Redwood 1, R1	4.05	30.7	1	0.887
Seconds, Saybolt Universal SSU	4.62	35.11	1.14	1

The above factors apply for values above 60cSt

17.3.17 Energy

Quantity designations: E, W, Q, L, U depending upon the type of energy.

SI unit: Joule (J).

Normal multiple units: TJ, GJ, MJ, kJ, mJ.

Since 1 J = 1 Nm = 1 Ws then Nm and Ws can also be used for all types of energy. The unit Joule should, however, be used for expressing all types of energy.

1 erg = 0.1 × 10⁻⁶ J.

J Joule	kWh kilowatt hour	kgf m kilogram- force metre	kcal kilo- calorie	ch h metric horse- power hour	ft. lbf (foot pound- force)	Btu (British thermal unit)
1	0.27778 · 10 ⁻⁶	0.10197	0.23885 · 10 ⁻³	0.37767 · 10 ⁻⁶	0.73756	0.94782 · 10 ⁻³
3.6 · 10 ⁶	1	0.36710 · 10 ⁶	859.85	1.3596	2.6552 · 10 ⁶	3.4121 · 10 ³
9.8066	2.7241 · 10 ⁻⁶	1	2.3423 · 10 ⁻³	3.7037 · 10 ⁻⁶	7.2330	9.2949 · 10 ⁻³
4.1868 · 10 ³	1.163 · 10 ⁻³	426.94	1	1.5812 · 10 ⁻³	3.0880 · 10 ³	3.9683
2.6478 · 10 ⁶	0.73550	0.27 · 10 ⁶	632.42	1	1.9529 · 10 ⁶	2.5096 · 10 ³

J Joule	kWh kilowatt hour	kgf m kilogram- force metre	kcal kilo- calorie	ch h metric horse- power hour	ft. lbf (foot pound- force)	Btu (British thermal unit)
1.3558	0.37662 · 10 ⁻⁶	0.13826	0.32383 · 10 ⁻³	0.51206 · 10 ⁻⁶	1	1.2851 · 10 ⁻³
1.0551 · 10 ³	0.29307 · 10 ⁻³	107.59	0.25200	0.39847 · 10 ⁻³	778.17	1

17.3.18 Power

Quantity designation: P.

SI unit: Watt (W).

Normal multiple units: GW, MW, kW, mW, W.

W	kgf m/s	kcal/s	kcal/h	ch metric horse- power	hp horse- power	ft lbf/s	Btu/h
1	0.10197	0.23885 · 10 ⁻³	0.85985	1.3596 · 10 ⁻³	1.3410 · 10 ⁻³	0.73756	3.4121
9.8066	1	2.3423 · 10 ⁻³	8.4322	13.333 · 10 ⁻³	13.151 · 10 ⁻³	7.2330	33.462
4.1868 · 10 ³	426.94	1	3.6 · 10 ³	5.6925	5.6146	3.0880 · 10 ³	14.286 · 10 ³
1.163	0.11859	0.27778 · 10 ⁻³	1	1.5812 · 10 ⁻³	1.5596 · 10 ⁻³	0.85779	3.9683
735.50	75	0.17567	632.42	1	0.98632	542.48	2.5096 · 10 ³
745.70	76.040	0.17811	641.19	1.0139	1	550	2.5444 · 10 ³
1.3558	0.13826	0.32383 · 10 ⁻³	1.1658	1.8434 · 10 ⁻³	1.8182 · 10 ⁻³	1	4.6262
0.29307	29.885 · 10 ⁻³	69.999 · 10 ⁻⁶	0.25200	0.39847 · 10 ⁻³	0.39302 · 10 ⁻³	0.21616	1

17.3.19 Flow

Quantity designation: q_v.

SI unit: cubic metre per second (m³/s).

Non-SI units: l/s, ml/s, m³/h.

l gallon/ min lgpm	US gallon/ min USgpm	barrel/ day bpd	m ³ /s	m ³ /h	l/s	l/min
1	1.2009	41.175	75.768 · 10 ⁻⁶	272.76 · 10 ⁻³	75.768 · 10 ⁻³	4.5461
0.83268	1	34.286	63.09 · 10 ⁻⁶	227.12 · 10 ⁻³	63.09 · 10 ⁻³	3.7854
24.286 · 10 ⁻³	29.167 · 10 ⁻³	1	1.84 · 10 ⁻⁶	6.6244 · 10 ⁻³	1.84 · 10 ⁻³	110.41 · 10 ⁻³
13.198 · 10 ³	15.85 · 10 ³	543.44 · 10 ³	1	3600	1000	60000
3.6662	4.4029	150.95	277.78 · 10 ⁻⁶	1	277.78 · 10 ⁻³	16.667
13.198	15.85	543.44	1.0 · 10 ⁻³	3.6	1	60
219.97 · 10 ⁻³	264.17 · 10 ⁻³	9.0573	16.667 · 10 ⁻⁶	60 · 10 ⁻³	16.667 · 10 ⁻³	1

1 barrel = 42 US gallon

17.3.20 Temperature

Absolute temperature: Quantity designation: T.

SI unit: Kelvin (K).

Temperature: Quantity designation: t.
unit degree Celsius (Centigrade) (°C).

	Kelvin*** scale	Celsius scale	Rankine scale	Fahrenheit* scale	Physical relation- ship
Relative temperature value	0 K	- 273.15 °C	0 °R	- 459.67 °F	Absolute zero
	273.15 K	0 °C	491.67 °R	32 °F	Melting point of ice*
	273.16 K	0.01 °C	491.688 °R	32.018 °F	Triple point of water*
	373.15 K	100 °C	671.67 °R	212 °F	Boiling point of water*
Relative temperature intervals (diffs)	1 K 0.55556 K	1 °C 0.55556 °C	1.8 °R 1 °R	1.8 °F 1 °F	

* For defined conditions

** Value in °C = $\frac{1}{1.8}$ (value in °F -32) = (value in K -273.15)

*** Value in K = $\frac{5}{9}$ x (value in °R)

17.4 Other conversion factors

17.4.1 Hardness

Hardness is not defined within the SI system. The following table can be used for conversion between the popular systems used.

Tensile strength	Vickers hardness (F ≥ 98 N)	Brinell hardness	Rockwell hardness	
N/mm ²	HV	BHN	HR _B	HR _C
200	63	60		
210	65	62		
220	69	66		
225	70	67		
230	72	68		
240	75	71		
250	79	75		
255	80	76		
260	82	78		
270	85	81	41	
280	88	84	45	
285	90	86	48	
290	91	87	49	
300	94	89	51	
305	95	90	52	
310	97	92	54	
320	100	95	56	
330	103	98	58	
335	105	100	59	
340	107	102	60	
350	110	105	62	
360	113	107	63.5	
370	115	109	64.5	
380	119	113	66	
385	120	114	67	
390	122	116	67.5	
400	125	119	69	
410	128	122	70	
415	130	124	71	
420	132	125	72	
430	135	128	73	
440	138	131	74	
450	140	133	75	
460	143	136	76.5	
465	145	138	77	
470	147	140	77.5	
480	150	143	78.5	

Tensile strength	Vickers hardness (F ≥ 98 N)	Brinell hardness	Rockwell hardness	
N/mm ²	HV	BHN	HR _B	HR _C
490	153	145	79.5	
495	155	147	80	
500	157	149	81	
510	160	152	81.5	
520	163	155	82.5	
530	165	157	83	
540	168	160	84.5	
545	170	162	85	
550	172	163	85.5	
560	175	166	86	
570	178	169	86.5	
575	180	171	87	
580	182	172		
590	184	175	88	
595	185	176		
600	187	178	89	
610	190	181	89.5	
620	193	184	90	
625	195	185		
630	197	187	91	
640	200	190	91.5	
650	203	193	92	
660	205	195	92.5	
670	208	198	93	
675	210	199	93.5	
680	212	201		
690	215	204	94	
700	219	208		
705	220	209	95	
710	222	211	95.5	
720	225	214	96	
730	228	216		
740	230	219	96.5	
750	233	221	97	
755	235	223	97.5	
760	237	225		
770	240	228	98	
780	243	231		21
785	245	233		
790	247	235	99	
800	250	238	99.5	22
810	253	240		
820	255	242		23
830	258	245		
835	260	247		24
840	262	249		
850	265	252		
860	268	255		25
865	270	257		
870	272	258		26
880	275	261		
890	278	264		
900	280	266		27
910	283	269		
915	285	271		
920	287	273		28
930	290	276		
940	293	278		29
950	295	280		
960	299	284		
965	300	285		
970	302	287		30

Tensile strength	Vickers hardness (F ≥ 98 N)	Brinell hardness	Rockwell hardness	
			HR _B	HR _C
N/mm ²	HV	BHN		
980	305	290		
990	308	293		
995	310	295		31
1000	311	296		
1010	314	299		
1020	317	301		32
1030	320	304		
1040	323	307		
1050	327	311		33
1060	330	314		
1070	333	316		
1080	336	319		34
1090	339	322		
1095	340	323		
1100	342	325		
1110	345	328		35
1120	349	332		
1125	350	333		
1130	352	334		
1140	355	337		36
1150	358	340		
1155	360	342		
1160	361	343		
1170	364	346		37
1180	367	349		
1190	370	352		
1200	373	354		
1210	376	357		38
1220	380	361		
1230	382	363		39
1240	385	366		
1250	388	369		
1255	390	371		
1260	392	372		40
1270	394	374		
1280	397	377		
1290	400	380		
1300	403	383		41
1310	407	387		
1320	410	390		
1330	413	393		42
1340	417	396		
1350	420	399		
1360	423	402		43
1370	426	405		
1380	429	408		
1385	430	409		
1390	431	410		
1400	434	413		44
1410	437	415		
1420	440	418		
1430	443	421		
1440	446	424		
1450	449	427		45
1455	450	428		
1460	452	429		
1470	455	432		
1480	458	435		46
1485	460	437		
1490	461	438		
1500	464	441		
1510	467	444		

Tensile strength	Vickers hardness (F ≥ 98 N)	Brinell hardness	Rockwell hardness	
			HR _B	HR _C
N/mm ²	HV	BHN		
1520	470	447		
1530	473	449		47
1540	476	452		
1550	479	455		
1555	480	456		
1560	481	457		
1570	484	460		48
1580	486	462		
1590	489	465		
1595	490	466		
1600	491	467		
1610	494	470		
1620	497	472		49
1630	500	475		
1640	503	478		
1650	506	481		
1660	509	483		
1665	510	485		
1670	511	486		
1680	514	488		50

Values based on DIN 50150.

17.4.2 Material toughness

Material toughness is not defined by SI. Most materials are assessed by conducting impact testing. Two differing test methods can be used with various sizes and styles of test specimen. The following table can be used as a **guide** to the relative toughness of the various tests:

Charpy V notch kgm/cm ²	Charpy V notch ft lb	Charpy V notch Joule	Izod ft lb
0.4	2.3	3.1	2.5
0.9	5.2	7	6.4
1.5			10.8
2.2			16
3.1	18	24.4	21.5
4.1	23.8	32.2	27.8
5.2	30	40.6	34.1
6.5	37.7	51	40.4
8.0	46.4	92.9	46.7
9.4	54.5	73.9	53
10.9	63	85.4	59.3
12.6			65.6
14.1	82	111	71.9
15.8			78.2
17.7	102	138	84.5
19.4			90.8
21.1	122	165	97.1
23.0	134	182	103.4

17.5 Normal quantities and units used in pump technology

Quantity		Recommended unit	
Name	Symbol	Name	Units
Area	A	square metre square centimetre square millimetre	m ² cm ² mm ²
Compressibility	χ	reduction in unit volume per bar differential pressure	bar ⁻¹
Density	ρ	kilogram per cubic metre gram per cubic decimetre	kg/m ³ g/dm ³
Energy	E	Joule kiloJoule MegaJoule	J kJ MJ
Flow (1)	q _v	litre per second litre per minute litre per hour cubic metre per hour	l/s l/min l/h m ³ /h
Force	F	Newton kiloNewton MegaNewton	N kN MN
Frequency	f	Hertz kiloHertz MegaHertz	Hz kHz MHz
Head (suction, discharge, differential)	H	metre	m
Length	l	metre millimetre micron	m mm μm
Mass (weight)	m	tonne kilogram gram	tonne kg g
MIP (Minimum inlet pressure)	MIP	bar (gauge)	bar
Moment of inertia	J	kilogram metre squared	kgm ²
NPIP (Net positive inlet pressure)	NPIP	bar	bar
NPSH (Net positive suction head)	NPSH	metre	m
Power	P	Watt kiloWatt MegaWatt	W kW MW
Pressure (absolute or gauge)	p	bar	bar
Shaft speed	n	revolutions per second revolutions per minute revolutions per hour	r/s r/min r/h
Stress	σ τ	MegaNewton per square metre	MN/m ²
Temperature	T	degree Celsius	°C
Time	t	second minute hour	s min h
Torque	T	Newton metre kiloNewton metre MegaNewton metre	Nm kNm MNm
Velocity	v	metre per second	m/s
Viscosity, dynamic	η	Poise centiPoise	P cP
Viscosity, kinematic	μ	Stoke centiStoke	St cSt

(1) Pumps handle liquid by volume.
The user must convert mass flow to volume flow.

17.6 Useful references

Hydraulic Institute, 9 Sylvan Way, Parsippany NJ, 07054 USA
Tel: 973 267 9700, Fax: 973 2679055, www.pumps.org.

VDMA (German Engineering Federation), Lyoner Straße 18, D-60528 Frankfurt, Germany, Tel: 069 66 03-0, www.vdma.org.

BPMA, (British Pump Manufacturers Association), The McLaren Building 35 Dale End, Birmingham, B4 7LN, UK, Tel: 0121 200 1299 Fax: 0121 200 1306, Email: enquiry@bpma.org.uk.

American Bureau of Shipping, ABS, 16855 Northchase Drive, Houston, TX 77060 USA Tel: 281 877 5800, Fax: 281 877 5803, www.eagle.org.

Det Norske Veritas DNV, Veritasveien 1, N-1322 Høvik Norway, Tel: 067 57 99 00, Fax: 067 57 99 11, www.dnv.com.

Lloyd's Register (LR), 71 Fenchurch Street, London EC3M 4BS, UK, Tel: 020 7709 9166, Fax: 020 7488 4796, www.lr.org.

Bureau International des Poids et Mesures (BIPM), Pavillon de Breteuil, F-92312 Sèvres Cedex, France, www.bipm.fr.

Office of Public Sector Information (OPSI), Admiralty Arch, North Side, The Mall, London, SW1A 2WH, UK, Tel: 01603 723011, www.opsi.gov.uk.

The Stationery Office Ltd (TSO) UK, Tel: 0870 242 2345, Email: esupport@tso.co.uk, www.tsoshop.co.uk.

EFTA (European Free Trade Association), 9-11, rue de Varembe, CH-1211 Geneva 20 Switzerland, Tel: 022 332 2626, Fax: 022 332 2699, www.secretariat.efta.int.

Europump, Diamant Building, Blvd. A. Reyers 80, B-1030 Brussels, Belgium, Tel: 02 7068230, Fax: 02 7068253, www.europump.org.

European Hygienic Engineering & Design Group (EHEDG), Avenue Grand Champ, 148 B-1150 Brussels, Belgium, Tel: 32 02 7617408, www.ehedg.org.

NAFEM (North American Association of Foodservice Equipment Manufacturers), 161 North Clark Street, Suite 2020, Chicago, IL 60601, USA, Tel: 312.821.0201, Fax: 312.821.0202, www.nafem.org.

Buyers' guide

18

18.1 Introduction

18.2 Company names and addresses

Detailed company information, listed alphabetically by country

18.3 Rotodynamic pumps

Companies listed alphabetically by pump type

18.4 Positive displacement pumps

Companies listed alphabetically by pump type

18.5 Other pumps

Companies listed alphabetically by pump type

18.6 Ancillary products and services

Companies listed alphabetically by product and/or service

18.5 Trade names

Companies listed alphabetically by Trade name

18.1 Introduction

The Buyers' Guide summarises the various pump types, divided into three groups:

- Rotodynamic pumps
- Positive displacement pumps
- Other pumps

The Guide has been grouped in such a way to impose boundary limits on pump types and the operating conditions available, with the aim of simplifying the choice of supplier from the user's point of view.

The Buyers' Guide covers all pump types, followed by ancillary products and services. Trade names are comprehensively listed too. It is preceded by the names and addresses and contact details of all companies appearing in the Guide. They are listed alphabetically, by country.

It is strongly recommended that direct contact with the relevant companies is made to ensure that their details are clarified wherever necessary.

Company names and addresses, Section 18.2

Detailed company information, listed alphabetically by country.

Rotodynamic pumps, Section 18.3

Companies listed alphabetically by pump type.

Positive displacement pumps, Section 18.4

Companies listed alphabetically by pump type.

Other pumps, Section 18.5

Companies listed alphabetically by pump type.

Ancillary products and services, Section 18.6

Companies listed alphabetically by product and/or service.

Trade names, Section 18.7

Companies listed alphabetically by Trade name or product name.

18.2 Company names and addresses

Detailed company information, listed alphabetically by country

ARGENTINA (AR)

Motorarg SA
Pcia de Buenos Aires
Valentin Alsina
Veracruz (B1822BGP)
Argentina
Tel: 0420 87717
Fax: 0420 81080
Email: motorarg@motorarg.com.ar
Web: www.motorarg.com.ar

AUSTRALIA (AU)

Acromet (Aust) Pty Ltd
14 Winterton Road, Box 1105
Clayton
VIC 3168
Australia
Tel: 03 9544 7333
Fax: 03 9543 6706
Email: chemex@acromet.com.au
Web: www.acromet.com.au

Batescrew Pumps
Newell Highway
Tocumwal
NSW 2714
Australia
Tel: 03 587 42101
Fax: 03 587 42084
Email: sales@batescrew.com
Web: www.batescrew.com

Davey Products Pty Ltd
6 Lakeview Drive
Scoresby
VIC 3179
Australia
Tel: 03 9730 9121
Fax: 03 9753 4248
Email: export@davey.com.au
Web: www.davey.com.au

EBS-Ray Pumps Pty Ltd
628 Pittwater Road
Brookvale
Sydney
NSW 2100
Australia
Tel: 02 9905 0234
Fax: 02 9938 3825
Email: nswsales@ebsraypumps.com.au
Web: www.ebsraypumps.com.au

Engineered Products Group Pty Ltd (EPG)
31 Powers Road
Seven Hills
NSW 2147
Australia
Tel: 02 9830 2222
Fax: 02 9830 2384
Email: gateway@epg.com.au
Web: www.epg.com.au

Grundfos Pumps Pty Ltd
515 South Road
Regency Park

SA 5010
Australia
Tel: 08 8461 4611
Email: contact-au@grundfos.com
Web: www.grundfos.com

Kelair Pumps Australia Pty Ltd
Gateway Estate
215 Walters Road
Arndell Park
NSW 2128
Australia
Tel: 02 9678 9466
Fax: 02 9678 9455
Email: kelair@kelairpumps.com.au
Web: www.kelair.com.au

Mono Pumps (Australia) Pty Ltd
Mono House, 338-348 Lower Dandenong Road
Mordialloc
VIC 3195
Australia
Tel: 03 9580 5211
Fax: 03 9580 6659
Email: ozsales@mono-pumps.com
Web: www.mono-pumps.com

Robertson Technology Pty Ltd
PO Box 493
Joondalup DC
Joondalup
WA 6919
Australia
Tel: 08 9300 0844
Fax: 08 9300 2611
Email: mail@pumpmonitor.com
Web: www.pumpmonitor.com

TKL
26 Faigh Street
Mulgrave
VIC 3170
Australia
Tel: 03 9562 0744
Fax: 03 9562 2816
Email: dick_stevenson@flowserve.com
Web: www.tkl.com.au

Tyco - Southern Cross Plant
8616 Warrego Highway Corner Roches Road
Withcott
QLD 4352
Australia
Tel: 01800 888 909
Fax: 01800 637 867
Email: southerncross@typac.com.au
Web: www.southerncross.com.au

United Pumps Australia (UPA)
31 Western Avenue
Sunshine
VIC 3020
Australia
Tel: 03 93126566
Fax: 03 93126371
Email: unitedpumps@unitedpumps.com.au
Web: www.unitedpumps.com.au

AUSTRIA (AT)

ABS Pumpen GmbH
IZ-NÖ-Süd
Strasse 2, M27
A-2351 Wiener Neudorf
Austria
Tel: 02236 64261
Fax: 02236 64266
Email: info@absgroup.com
Web: www.absgroup.com

Andritz AG
Stattegger Strasse 18
A-8045 Graz
Austria
Tel: 0316 6902 0
Fax: 0316 6902 406
Email: irmtraut.pfingstl@andritz.com
Web: www.andritz.com

AxFlow GmbH
Wienerstrasse 253
A-8051 Graz
Austria
Tel: 0316 683509
Fax: 0316 683492
Email: office@axflow.at
Web: www.axflow.at

Bühler Hochdrucktechnik GmbH
PO Box 27 Werk-VI-Strasse
A-8605 Kapfenberg
Austria
Tel: 03862 303300
Fax: 03862 303304
Email: bohler.office@bhdt.at
Web: www.bhdt.at

Grundfos Pumpen Vertrieb GmbH
Grundfosstrasse 2
A-5082 Grödig/Salzburg
Austria
Tel: 06246 8830
Email: info-austria@grundfos.com
Web: www.grundfos.com

Hauke GmbH & Co KG
Postfach 103
Cumberlandstrasse 46-50
A-4810 Gmunden
Austria
Tel: 07612 637580
Fax: 07612 64133
Email: hauke.gesmbh@aon.at
Web: www.hauke.at

Kräutler GmbH & Co
Bildgasse 40
A-6893 Lustenau
Austria
Tel: 05577 866440
Fax: 05577 88433
Web: www.kral.at

Sterling Fluid Systems (Austria)
Oberlaaer Strasse 228
A-1100 Vienna
Austria
Tel: 01 680 050

Fax: 01 680 0521
Email: sales_austria@sterlingsihi.de
Web: www.sterlingfluid.com

**Pumpenfabrik Ernst Vogel GmbH,
ITT Industries**

Ernst Vogel-Strasse 2
 A-2000 Stockerau
 Austria
Tel: 02266 6040
Fax: 02266 65311
Email: info@vogel-pumpen-ittind.com
Web: www.vogel-pumps.com

BELGIUM

(BE)

ABS Pumps NV/SA

Haachtsesteenweg 56
 B-1831 Diegem
 Belgium
Tel: 02 725 7900
Fax: 02 725 7119
Email: info@absgroup.com
Web: www.absgroup.com

Alfons de Backer & Co

Kasteeldreef 1
 B-9230 Wetteren
 Belgium
Tel: 09 369 3496
Fax: 09 369 5752
Email: dbjm@duba.be
Web: www.duba.be

Clasal

Ruddervoordsestraat 82
 B-8210 Zedelgem
 Belgium
Tel: 050 27 8253
Fax: 050 27 5494
Email: info@clasal.be
Web: www.clasal.be

Ensival-Moret

Rue de Hodister 44
 B-4860 Wegnez-Pepinster
 Belgium
Tel: 087 46 8111
Fax: 087 46 8100
Email: emwegnez@em-pumps.com
Web: www.ensival.com

Packo Inox NV

Cardijnlaan 10
 B-8600 Diksmuide
 Belgium
Tel: 051 519280
Fax: 051 519299
Email: diksmuide@packo.com
Web: www.packo.com

Sterling Fluid Systems (Belgium) NV

Zone Gosset, 't Hofveld 1
 B-1702 Groot-Bijgaarden
 Belgium
Tel: 02 481 7711
Fax: 02 481 7737
Email: sales@sterlingfluidsystems.be
Web: www.sterlingfluid.com

Toyo Pumps Europe

Parc Industriel Sud – Zone II
 Rue de l'industrie 41

B-1400 Nivelles
 Belgium
Tel: 067 64 5537
Fax: 067 64 5531
Email: info@toyopumpseurope.com
Web: www.toyopumpseurope.com

Vandezande

Zeepziederijstraat 5
 Industrierterrein Kaaskerke
 B-8600 Diksmuide
 Belgium
Tel: 051 500117
Fax: 051 504117
Email: info@vandezande.com
Web: www.vandezande.com

BRAZIL

(BR)

**ABS Industria de Bombas
Centrifugas Ltda**

Rua Hasdrubal, Bellegard 701 CIC
 CEP 81460 - 120 Curitiba - Paraná
 Brazil
Tel: 041 2108 8100
Fax: 041 3348 1879
Email: info@absgroup.com
Web: www.absgroup.com

Mark Grundfos Ltda

Av Humberto de Alencar
 Castelo Branco 630
 09850-300 São Sernardo do Campo SP
 Brazil
Tel: 011 4393 5533
Email: stiegs@grundfos.com
Web: www.grundfos.com

Omel Ltda

Rua Silvio Manfredi 201
 Guarulhos
 Sao Paulo 07241-000
 Brazil
Tel: 011 6413 5400
Fax: 011 6412 5056
Email: omel@omel.com.br
Web: www.omel.com.br

CANADA

(CA)

ABS Pumps Corporation

1215 Meyerside Drive, Unit 7
 Mississauga
 Ontario L5T 1H3
 Canada
Tel: 905 670 4677
Fax: 905 670 3709
Email: info@absgroup.com
Web: www.absgroup.com

Eagle Pump & Compressor Ltd

7025 - 5th Street SE
 Calgary
 Alberta
 T2H 2G2
 Canada
Tel: 403 253 0100
Fax: 403 253 8884
Email: bcsavosi@eagle-pc.com
Web: www.eagle-pc.com

Hayward Gordon

6660 Campobello Road
 Mississauga

Ontario
 L5N 2L9
 Canada
Tel: 905 567 6116
Fax: 905 567 1706
Email: info@haywardgordon.com
Web: www.haywardgordon.com

Kudu Industries Inc

9112 40th Street SE
 Calgary AB
 T2C 2P3
 Canada
Tel: 403 279 5838
Fax: 403 279 2192
Email: ray_mills@kudupump.com
Web: www.kudupump.com

Monarch Industries Ltd

51 Burmac Road
 Winnipeg
 Manitoba R3C 3E4
 Canada
Tel: 204 786 7921
Fax: 204 889 9120
Email: enquiries@monarchindustries.com
Web: www.monarchindustries.com

Nova Magnetics Burgmann Ltd

One Research Drive
 Dartmouth
 Nova Scotia
 B2Y 4M9
 Canada
Tel: 902 465 6625
Fax: 902 465 6629
Email: info@novamagnetics.ca
Web: www.novamagnetics.ca

Sunmotor International Ltd

5031 50 Sreet
 Olds
 Alberta
 T4H 1R8
 Canada
Tel: 403 556 8755
Fax: 403 556 7799
Email: sunmotor@telusplanet.net
Web: www.sunpump.com

Vican Pump Company

661 Grove Avenue
 Windsor
 ON N9A 6M3
 Canada
Tel: 519 256 5438
Fax: 519 256 5070
Email: gbornais@idexcorp.com
Web: www.vikingpumpcanada.com

CHINA

(CN)

ABS Shanghai Co Ltd

Room 3005-06 Zhong Bao Mansion
 No 166, Lu Jia Zui Road (E)
 Pu Dong New District
 CN-200120 Shanghai
 China
Tel: 021 6888 2900
Fax: 0215882 6708
Email: info@absgroup.com
Web: www.absgroup.com

**ABS Shanghai Co Ltd
Beijing Liaison Office**

Room 1701, Kuntai International Mansion
No 12 2nd, Chaowai Street
Beijing 100020
China
Tel: 010 5879 0009
Fax: 010 5879 0512
Email: info@absgroup.com
Web: www.absgroup.com

Benxi Water Pump Factory

16 Digong Road
Mingshan
Benxi 117022
China
Tel: 0414 483 7107
Fax: 0414 482 8402
Email: bxspump@online.ln.cn

Dalian Danai Pumps Ltd

250 Huabei Road
Shahekou District
Dalian
China
Tel: 0411 440 3456
Fax: 0411 440 3008
Email: dapp@denecbn.com
Web: www.denecbn.com

**Hunan XD Changsha
Pump Works Co Ltd**

522 Furong Road (M)
Changsha
Hunan 410015
China
Tel: 0731 5215460
Email: postmaster@cbpump.com
Web: www.cbump.com.cn

Jiangsu Haishi Pump Co Ltd

1 Xinqiao Road
Xinqiao Town
Jingjiang City
Jiangsu Province 214537
China
Tel: 0523 4321008
Fax: 0523 4321103
Email: sales@haishipump.com
Web: www.haishipump.com

Junty Industries Ltd

D-601, Guoheng Jiye Mansion
No 7 Bei Tu Cheng Xi Lu
Chaoyang district
Beijing 100029
China
Tel: 010 8227 5316
Fax: 010 8227 5331
Email: info@sealchina.com
Web: www.SeaChina.com

Mono Pumps (China) Ltd

Room 2303, Capital Mansion
No 6 Xin Yuan Southern Road
Chao Yang District
Beijing 100004
China
Tel: 010 6461 1115
Email: monobeijing@natoil.com
Web: www.mono-pumps.com

PCM Asia Pacific

Unit 10A, 19-21, Shanghaimeart
2299 Yanan Road (West)

200336 Shanghai
China

Tel: 021 6236 2521
Fax: 021 6236 2428
Email: pcmchina@pcmpompes.com
Web: www.pcmpompes.com

PCM Moineau Oilfield

Room 608, Inter Continental Plaza
16 Andelu, Dongcheng District
100011 Beijing
China
Tel: 010 8488 2003
Fax: 010 8488 2005
Email: jma@pcmpompes.com
Web: www.pcmpompes.com

**Shanghai Liansheng
Pump Manufacture Co Ltd**

2646 Lian Xi Highway
Liansheng Town, Qingpu District
Shanghai 201722
China
Tel: 021 59271627
Fax: 021 5927 1080
Email: shlsby@shanghai-liansheng.com
Web: www.shanghai-liansheng.com

**Shanghai Shenbao
Industrial Pump Co Ltd**

2500 Beisong Road
Minghang District
Shanghai 201111
China
Tel: 021 6409 5555
Fax: 021 6409 5040
Web: www.shenbao-pump.com

**Shanxi Jishan Qinglong
Pump Industry Co Ltd**

Floor 8, Tower B, New Energy Building
Nanyou Road
Shenzhen
Guangdong 518054
China
Tel: 075 5664 1103
Fax: 075 5664 5976
Email: info@chinesesource.com
Web: www.66daji.com

**Shijiazhuang Pump
Industry Group Co Ltd**

19 Heping East Road
Shijiazhuang
Hebei 050011
China
Tel: 0311 6082947
Fax: 0311 6033212
Email: spw@heinfo.net
Web: www.cspw.com

Tangshan Pump Factory

104 Da Qing Road
Tangshan
Hebei 063000
China
Tel: 0315 3205818
Fax: 0315 3207547
Email: tspump@tspump.com
Web: www.tspump.com

**Tianjin Pumps & Machinery
Group Co Ltd**

10 Guoyuan Nan Road
Beichen District

Tianjin
China

Tel: 022 26833413
Fax: 022 2639 1556
Email: export@ctppumps.com
Web: www.ctppumps.com

Tsurumi (Shanghai) Co Ltd

Room 1201 Building D
No 80 Caobao Road
Xuhui Shanghai 200235
China
Tel: 021 6432 6010
Fax: 021 6432 6013
Email: sh.sales@tsurumipump.com.cn

Ture International Industrial Ltd

No 101, An Kang Lou
Feng an Hua Yuan, Ge Xin Road
Guang Zhou 510250
China
Tel: 020 3409 6252
Fax: 020 3434 2272
Email: helhua@pub.guangzhou.gd.cn
Web: www.seocapump.com

Hangzhou SRT Pump Co Ltd

No 2, 20 Street, Xiashan Economic &
Technical Development Zone
Hangzhou 310018
Zhejiang Province
China
Tel: 0571 8657 1014
Fax: 0571 8657 1015
Email: export@srt-pump.com
Web: www.srt-pump.com

CZECH REPUBLIC (CZ)**AxFlow sro**

Utováren 261
CZ-10200 Prague
Czech Republic
Tel: 02 101180
Fax: 02 72101189
Email: axflow@axflow.cz
Web: www.axflow.cz

BBA Hranice sro

Belotin 287
CZ-753 64 Belotin
Czech Republic
Tel: 05 8169 9311
Fax: 05 8169 9332
Email: bbahranice@bbahranice.cz
Web: www.bbahranice.cz

Kovoplast Chlumec nad Cidlinou as

Kozelkova 131
CZ-503 51 Chlumec n. C
Czech Republic
Tel: 049 548 4543
Fax: 049 548 5230
Email: kovoplast@kovoplast.cz
Web: www.kovoplast.cz

Ondrejovicka Strojirna sro

Ondrejovice
CZ-793 76 Zlate Hory
Czech Republic
Tel: 064 542 5151
Fax: 064 542 5462
Email: ondrstroj@ondrstroj.cz
Web: www.ondrstroj.cz

Sigma Group AS
ul Jana Sigmunda 79
CZ-78350 Lutín
Czech Republic
Tel: 058 565 2150
Fax: 058 594 4258
Web: www.sigma.cz

Sigmia Trading International
Kosmonautu 6
CZ-77231 Olomouc
Czech Republic
Tel: 058 552 4510
Fax: 058 522 7074

Siwatec AS
Svobody 43/39
CZ-77200 Olomouc
Czech Republic
Tel: 058 522 4104
Fax: 058 522 3984
Email: export@siwatec.cz
Web: www.siwatec.cz

DENMARK

(DK)

APV Fluid Handling Horsens
Ternevej 61-63
DK-8700 Horsens
Denmark
Tel: 075 643777
Fax: 075 643868
Email: soren.c.steensen@invensys.com
Web: www.apv.com

AxFlow A/S
Solvang 6
DK-3450 Allerød
Denmark
Tel: 07010 3550
Fax: 07010 3555
Email: axflow@axflow.dk
Web: www.axflow.dk

Desmi A/S
Tagholm 1
DK-9400 Nørresundby
Denmark
Tel: 096 328111
Fax: 098 175499
Email: desmi@desmi.com
Web: www.desmi.com

Dominator Aps
Rønnebærvej 2
DK-3200 Helsingør
Denmark
Tel: 048 796915
Fax: 048 796912
Email: info@dominator.dk
Web: www.dominator.dk

Flexicon A/S
Frejasvej 2-6
DK-4100 Ringsted
Denmark
Tel: 057 671155
Fax: 057 670541
Email: flexicon@flexicon.dk
Web: www.flexicon.dk

Grundfos Management A/S
Poul Due Jensensvej 7

DK-8850 Bjerringbo
Denmark
Tel: 08750 6026
Email: astubkjaer@grundfos.com
Web: www.grundfos.com

Hamworthy Svaneøj A/S
Fabriksparken 6
PO Box 30
DK-9230 Svenstrup J
Denmark
Tel: 096 372200
Fax: 098 383156
Email: svanehoj@hamworthy.com
Web: www.hamworthy.com

Iron Pump A/S
PO Box 527
Generatorvej 10
DK-2730 Herlev
Denmark
Tel: 044 916788
Fax: 044 911644
Email: sales@ironpump.dk
Web: www.ironpump.dk

T Smedegaard A/S
Sydvestvej 57-59
DK-2600 Glostrup
Denmark
Tel: 043 961028
Fax: 043 631766
Email: info@smedegaard.dk
Web: www.smedegaard.dk

ESTONIA

(EE)

ABS Pumps AS
Paldiski mnt 125
Box 290
EE-0090 Tallinn
Estonia
Tel: 0656 3398
Fax: 0656 3385
Email: info@absgroup.com
Web: www.absgroup.com

FINLAND

(FI)

ABS Finland Oy
Turvekujä 6
FI-00700 Helsingfors
Finland
Tel: 07 5324 0300
Fax: 07 5324 0300
Email: info@absgroup.com
Web: www.absgroup.com

AxFlow Oy
Jokisuunkuja 3
FI-00560 Helsinki
Finland
Tel: 09 777 1930
Fax: 09 79 7550
Email: axflow@axflow.fi
Web: www.axflow.fi

Oy Kolmeks AB
PO Box 27
FIN-14201 Turenki
Finland
Tel: 03 5353531
Fax: 03 5353200

Email: export@kolmeks.fi
Web: www.kolmeks.fi

FRANCE

(F)

ABS France SAS
26 Allé du Plateau
F-93250 Villemomble
France
Tel: 01 49 35 24 50
Fax: 01 48 54 42 82
Email: info@absgroup.com
Web: www.absgroup.com

AxFlow SAS
Zone Industrielle du Saule Michaud
BP 42
F-37270 Montlouis-sur-Loire
France
Tel: 02 4745 84 58
Fax: 02 4745 14 34
Email: info@axflow.fr
Web: www.axflow.fr

DKM
Division of Clextral
PO Box 10, 1 Rue de Colonal Riez
F-42702 Firminy Cedex
France
Tel: 04 77 40 31 43
Fax: 04 77 89 43 94
Email: sales@dkm-pumps.com
Web: www.dkm-pumps.com

Fapmo
35-37 Rue Roger Salengro
F-62230 Outreau
France
Tel: 03 21 10 01 21
Fax: 03 21 80 46 88
Email: fapmo@fapmo.com
Web: www.nordnet.fr/fapmo

Milton Roy Europe
10 Grande Rue
F-27360 Pont Saint Pierre
France
Tel: 02 32 68 30 00
Fax: 02 32 68 30 93
Email: contact@miltonroy-europe.com
Web: www.miltonroy-europe.com

Optimex
269 rue de Montepy
F-69 210 Fleurieux sur l'Arbresle
France
Tel: 04 72 52 95 74
Fax: 04 72 52 95 75
Email: contact@optimex-pumps.com
Web: www.optimex.fr

PCM
17 rue Ernest Laval
BP 35
F-92173 Vanves
France
Tel: 01 41 08 15 15
Fax: 01 41 08 15 00
Email: pcm@pcmpompes.com
Web: www.pcmpompes.com

PEME-Gourdin SA
Allée Charles Victor Naudin
Parc d'activité Sophia Antipolis

F-06410 Biot
France
Tel: 04 93 00 66 00
Fax: 04 93 00 01 75
Email: commercial@peme-gourdin.com
Web: www.peme-gourdin.com

Sterling Fluid Systems (France) SAS
1-3 avenue Georges Politzer
PO Box 41
F-78193 Trappes
France
Tel: 01 34 82 39 00
Fax: 01 34 82 39 61
Email: sterling_sih@easynet.fr
Web: www.sterlingfluid.com

Sundyne International SA
Fluid Handling Division
13-15 Building Eiffel
Zone Industrielle de Dijon Sud
F-21600 Longvic Cedex
France
Tel: 03 80 38 33 00
Fax: 03 80 38 33 71
Email: european-sales@sundyne.com
Web: www.sundyne.com

GERMANY

(D)

Abel GmbH & Co KG
Abel-Twiete 1
D-21514 Büchen
Germany
Tel: 04155 8180
Fax: 04155 818499
Email: mail@abel.de
Web: www.abel.de

ABS Deutschland GmbH
Pützchens Chaussee 202
D-53229 Bonn
Germany
Tel: 02246 130
Fax: 02246 13200
Email: info@absgroup.com
Web: www.absgroup.com

ACD Cryo GmbH
Rheinauenstrasse 2
D-79415 Bad Bellingen
Germany
Tel: 07635 8105 0
Fax: 07635 8965
Email: sales@acderyo.com
Web: www.acdcryo.com

Alfons Haar Maschinenbau GmbH & Co
Fangdieckstrasse 67
D-22547 Hamburg
Germany
Tel: 040 833910
Fax: 040 844910
Email: sales@alfons-haar.de
Web: www.alfons-haar.de

Alldos GmbH
Reetzstrasse 85
D-76327 Pfinztal (Söllingen)
Germany
Tel: 07240 610
Fax: 07240 61177
Email: alldos.de@alldos.com
Web: www.alldos.de

Alltech Dosieranlagen GmbH
PO Box 120
D-76352 Weingarten
Germany
Tel: 07244 70260
Fax: 07244 1053
Email: info@alltech-dosieranlagen.de
Web: www.alltech-dosieranlagen.de

Allweiler AG
Allweilerstrasse 1
D-78315 Radolfzell
Germany
Tel: 07732 860
Fax: 07732 86436
Email: service@allweiler.de
Web: www.allweiler.de

Apollo Gössnitz GmbH
Walter-Rabold-Strasse 26
Gössnitz
D-04639 Gößnitz
Germany
Tel: 034493 770
Fax: 034493 77210
Email: info@apollo-goessnitz.de
Web: www.apollo-goessnitz.de

AxFlow GmbH
Neumannstrasse 2
D-40235 Düsseldorf
Germany
Tel: 0211 238060
Fax: 0211 2380620
Email: info@axflow.de
Web: www.axflow.de

Bavaria Fluidtec GmbH
Postfach 122
D-82213 Maisach
Germany
Tel: 08141 61180
Fax: 08141 611838
Email: info@bavariafluidtec.de
Web: www.bavariafluidtec.de

Behrens Pumpen
Von Thünen Strasse 7
D-28307 Bremen
Germany
Tel: 0421 486810
Fax: 0421 4868111
Email: sales@behrenspumpen.de

Bielomatik Leuze GmbH & Co
Daimlerstrasse 6-10
D-72639 Neuffen
Germany
Tel: 07025 120
Fax: 07025 12 200
Email: info@bielomatik.de
Web: www.bielomatik.com

Börger GmbH
Benningsweg 24
D-46325 Borken Weseke
Germany
Tel: 02862 910320
Fax: 02862 910346
Email: info@boerger-pumps.com
Web: www.boerger-pumps.com

Bornemann GmbH
Industriestrasse 2

D-31683 Obernkirchen
Germany
Tel: 05724 3900
Fax: 05724 390290
Email: diana.ruehle@bornemann.com
Web: www.bornemann.com

Burgmann Industries GmbH & Co KG
Aeussere Sauerlacher Strasse 6-10
D-82515 Wolfratshausen
Germany
Tel: 08171 230
Fax: 08171 231214
Email: info@de.eagleburgmann.com
Web: www.eagleburgmann.com

Delasco PCM GmbH
Wiesbadener Landstrasse 18
D-65203 Wiesbaden
Germany
Tel: 0611 609770
Fax: 0611 6097720
Email: info@delasco.de
Web: www.delasco.de

Desmi GmbH
Neuhöfer Strasse 23
D-21107 Hamburg
Germany
Tel: 040 7519847
Fax: 040 7522040
Email: rotan@rotan-pumpen.de
Web: www.rotan-pumpen.de

Dickow Pumpen KG
Siemenstrasse 22
D-84478 Waldkraiburg
Germany
Tel: 08638 6020
Fax: 08638 602200
Email: export@dickow.de
Web: www.dickow.de

**Düchting Pumpen
Maschinenfabrik GmbH**
Wilhelm-Düchting-Strasse 22
D-58453 Witten
Germany
Tel: 02302 9690
Fax: 02302 690443
Email: info@duechting.com
Web: www.deuechting.com

EDUR Pumpenfabrik GmbH & Co KG
Hamburger Chaussee 148-152
D-24113 Kiel
Germany
Tel: 0431 6898 68
Fax: 0431 6898 800
Email: info@edur.de
Web: www.edur-pumpen.de

Franz Eisele und Söhne GmbH & Co KG
Hauptstrasse 2-4
D-72488 Sigmaringen
Germany
Tel: 07571 1090
Fax: 07571 10988
Email: info@eisele.de
Web: www.eisele.de

Feluwa Pumpen GmbH
Beulertweg
D-54570 Mürtenbach
Germany

Tel: 065 94 10 0
Fax: 065 94 1640
Email: info@feluwa.de
Web: www.feluwa.com

Flux-Geräte GmbH
 Talweg 12
 D-75433 Maulbronn
 Germany
Tel: 07043 101 0
Fax: 07043 101 555
Email: export@flux-pumpen.de
Web: www.flux-pumpen.de

Fristram Pumpen
 F Stamp KG (GmbH & Co)
 PO Box 80 08 80
 D-21008 Hamburg
 Germany
Tel: 040 725560
Fax: 040 72 56166
Email: info@fristam.de
Web: www.fristam.com

Grundfos GmbH
 Schlüterstrasse 33
 D-40699 Erkrath
 Germany
Tel: 0211 929690
Email: wasserwirtschaft@grundfos.de
Web: www.grundfos.com

Arthur Habermann GmbH & Co KG
 PO Box 1640
 D-58406 Witten
 Germany
Tel: 02302 66060
Fax: 02302 690564
Email: mail@habermann-gmbh.de
Web: www.habermann-gmbh.de

Hanning & Kahl GmbH & Co KG
 PO Box 1342
 D-33806 Oerlinghausen
 Germany
Tel: 05202 707600
Fax: 05202 707629
Email: info@huk.hanning.com
Web: www.hanning-kahl.de

Hauhinco
 Beisenbruchstrasse 10
 D-45549 Sprockhövel
 Germany
Tel: 02324 7050
Fax: 02324 705222
Email: info@hauhinco.de
Web: www.hauhinco.com

Herborner Pumpenfabrik
 JH Hoffmann GmbH & Co
 Littau 3-5
 D-35745 Herborn
 Germany
Tel: 02772 9330
Fax: 02772 933105
Email: info@herborner-pumpen.de
Web: www.herborner-pumpen.de

Hermetic-Pumpen GmbH
 Gewerbestrasse 51
 D-79194 Gundelfingen
 Germany
Tel: 0761 58300
Fax: 0761 5830280

Email: hermetic@lederle-hermetic.com
Web: www.lederle-hermetic.com

Philipp Hilge GmbH & Co KG
 Hilgestrasse
 D-55294 Bodenheim
 Germany
Tel: 061 35750
Fax: 061 351737
Email: hilge@hilge.de
Web: www.hilge.de

Homa Pumpenfabrik GmbH
 Industriestrasse 1
 D-53819 Neunkirchen-Seelscheid
 Germany
Tel: 02247 7020
Fax: 02247 70244
Email: info@homa-pumpen.de
Web: www.homa-pumpen.de

Horn GmbH & Co KG
 Munketoft 42
 D-24937 Flensburg
 Germany
Tel: 0461 86960
Fax: 0461 869666
Email: info@horn-gmbh.de
Web: www.horn-gmbh.de

Hüdig GmbH & Co KG
 Heinrich Hüdig Strasse 2
 D-29227 Celle
 Germany
Tel: 05141 88450
Fax: 05141 86918
Email: info@huedig.de
Web: www.huedig.de

Indag Maschinenbau GmbH
 Ivenfleth 13
 D-25376 Borsfleth
 Germany
Tel: 04124 98760
Fax: 04124 987654
Email: info@indag.de
Web: www.indag.de

Iwaki Europe GmbH
 Siemensring 115
 D-47877 Willich
 Germany
Tel: 02154 925450
Fax: 02154 925455
Email: info@iwaki.de
Web: www.iwaki.de

Jabsco GmbH, ITT Industries
 Oststrasse 28
 D-22844 Norderstedt
 Germany
Tel: 040 5353730
Fax: 040 53537311
Web: www.jabsco.com

Jung Pumpen GmbH & Co
 Industriestrasse 4-6
 D-33803 Steinhagen
 Germany
Tel: 0520 4170
Fax: 0520 480368
Email: international@jung-pumpen.de
Web: www.jung-pumpen.de

Kächele GmbH
 Jahnstrasse 9
 D-73235 Weilheim/Teck
 Germany
Tel: 07023 1030
Fax: 07023 103240
Email: pumps@w-kaechele.de
Web: www.kaechele.de

Kamat Pumpen GmbH Co KG
 Salinger Feld 10
 D-58454 Witten-Annen
 Germany
Tel: 02302 89030
Fax: 02302 801917
Email: werner.potrafke@kamat.de
Web: www.kamat.de

Klaus Union GmbH & Co KG
 PO Box 101349
 D-44713 Bochum
 Germany
Tel: 0234 45950
Fax: 0234 432387
Email: info@klaus-union.de
Web: www.klaus-union.de

KNF Neuberger GmbH
 Alter Weg 3
 D-79112 Freiburg-Munzingen
 Germany
Tel: 07664 59090
Fax: 07664 2124
Email: info@knf.de
Web: www.knf.de

Körting Hannover AG
 Badenstedter Strasse 56
 D-30453 Hannover
 Germany
Tel: 0511 21290
Fax: 0511 2129223
Email: info@koerting.de
Web: www.koerting.de

Kracht GmbH
 Gewerbestrasse 20
 D-58791 Werdohl
 Germany
Tel: 02392 9350
Fax: 02392 935209
Email: info@kracht-hydraulik.de
Web: www.kracht-hydraulik.de

KSB AG
 Johann-Klein-Strasse 9
 D-67227 Frankenthal
 Germany
Tel: 06333 860
Fax: 06333 86 3401
Web: www.ksb.com

KTR Kupplungstechnik GmbH
 Rodder Damm 170
 D-48432 Rheine
 Germany
Tel: 05971 7980
Fax: 05971 798698
Email: sales@ktr.com
Web: www.ktr.com

Lederle GmbH
 Gewerbestrasse 53
 D-79194 Gundelfingen
 Germany

Tel: 0761 58300
Fax: 0761 5830180
Email: lederle@lederle-hermetic.com
Web: www.lederle-hermetic.com

Leistritz Pumpen GmbH
 PO Box 30 41
 D-90014 Nürnberg
 Germany
Tel: 0911 430360
Fax: 0911 4306490
Email: pumps@leistritz.de
Web: www.leistritz.com

LEWA GmbH
 Ulmer Strasse 10
 D-71229 Leonberg
 Germany
Tel: 07152 1140
Fax: 07152 1141303
Email: lewa@lewa.de
Web: www.lewa.com

Lutz-Jesco
 Am Bostelberge 19
 D-30900 Wedemark
 Germany
Tel: 0513 058020
Fax: 05130 580268
Email: info@jesco.de
Web: www.jesco.de

MASO Process-Pumpen GmbH
 PO Box 100
 D-74358 Illsfield
 Germany
Tel: 070 62 95600
Fax: 070 62 64593
Email: info@maso.de
Web: www.maso.de

Maximator GmbH
 Walkenrieder Strasse 15
 D-37449 Zorge/Harz
 Germany
Tel: 05586 8030
Fax: 05586 80340
Email: info@maximator.de
Web: www.maximator.de

Netzsch Mohnopumpen GmbH
 Geretsrieder Strasse 1
 D-84478 Waldkraiburg
 Germany
Tel: 08638 630
Fax: 08638 67981
Email: info@nmp.netzsch.com
Web: www.netzsch-pumps.com

Nikkiso Pumps Europe GmbH
 Nikkisostrasse
 D-63674 Altenstadt
 Germany
Tel: 06047 96490
Fax: 06047 9649 99
Email: info@nikkiso-pumps.com
Web: www.nikkiso-pumps.com

**Oddesse Pumpen-und
Motorenfabrik GmbH**
 Am Pappelwald 12
 D-39387 Oschersleben/Bode
 Germany
Tel: 03949 932467
Fax: 03949 932463

Email: info@oddesse.de
Web: www.oddesse.de

PCM Delasco GmbH
 Wiesbadener Landstrasse 18
 D-65203 Wiesbaden
 Germany
Tel: 0611 609770
Fax: 0611 6097720
Email: info@delasco.de
Web: www.delasco.de

**PF Pumpen und
Feuerlöschtechnik GmbH**
 Zechensteig 225
 D-09477 Jöhstadt
 Germany
Tel: 0373 43810
Fax: 0373 432287
Email: info@pfjoehstadt.de
Web: www.pfjoehstadt.de

ProMinent Dosiertechnik GmbH
 Im Schumachergewann 5-11
 D-69123 Heidelberg
 Germany
Tel: 06221 8420
Fax: 06221 842617
Email: info@prominent.de
Web: www.prominent.de

Prüftechnik Alignment Systems GmbH
 Oskar Messter Strasse 15
 D-85737 Ismaning
 Germany
Tel: 089 996160
Fax: 089 99616100
Email: sabine.kosma@prüftechnik.com
Web: www.prüftechnik.com

Rickmeier GmbH
 PO Box 1340
 D-58797 Balve
 Germany
Tel: 023751 9270
Fax: 023751 92726
Email: kontakt@rickmeier.de
Web: www.rickmeier.de

Rietschle Thomas Schopfheim GmbH
 Postfach 1260
 D-79642 Schopfheim
 Germany
Tel: 07622 3920
Fax: 07622 392300
Email: info.sch@rtpumps.com
Web: www.rietschle.com

Ritz Pumpenfabrik GmbH & Co KG
 P O Box 1780
 D-73507 Schwäbisch Gmünd
 Germany
Tel: 07171 6090
Fax: 07171 609287
Email: info@ritz.de
Web: www.ritz-pumpen.de

Ruhrpumpen GmbH
 Stockumer Strasse 28
 D-58453 Witten
 Germany
Tel: 02302 66103
Fax: 02302 661303
Email: info@ruhrpumpen.com
Web: www.ruhrpumpen.com

Scherzinger Pumps
 Bregstrasse 23-25
 D-78120 Furtwangen
 Germany
Tel: 07723 65060
Fax: 07723 650640
Email: info@scherzinger.de
Web: www.scherzinger.de

Schmalenberger GmbH & Co
 Im Schelmen 9-11
 D-72072 Tübingen
 Germany
Tel: 07071 700800
Fax: 07071 700810
Email: info@schmalenberger.de
Web: www.schmalenberger.de

Schroedahl-Arrap, Speciality Valves
 Schoenenbacker Strasse 4
 D-51580 Reichshof-Mittelagger
 Germany
Tel: 02265 00270
Fax: 02265 992727
Email: info@schroedahl.com
Web: www.schroedahl.com

seepex GmbH & Co KG
 PO Box 10 15 64
 D-46215 Bottrop
 Germany
Tel: 02041 9960
Fax: 02041 996400
Email: info@seepex.com
Web: www.seepex.com

Sero PumpSystems GmbH
 PO Box 69
 D-74907 Meckesheim
 Germany
Tel: 06226 92010
Fax: 06226 920140
Email: info@seroweb.de
Web: www.seroweb.de

Seybert & Rahier GmbH
 Sera-Strasse
 D-34376 Immenhausen
 Germany
Tel: 05673 39990
Fax: 05673 3999155
Email: info@sera-info.de
Web: www.sera-info.de

Speck-Pumpen
 Lohbachstrasse 6
 D-91161 Hilpoltstein
 Germany
Tel: 09174 9720
Fax: 09174 97249
Email: info@speck-pumpen.de
Web: www.speck-pumpen.de

Steinle Industripumpen GmbH
 Varnhagenstrasse 42
 D-40225 Düsseldorf
 Germany
Tel: 0211 333273
Fax: 0211 330755
Email: info@steinle-pumpen.de
Web: www.steinle-pumpen.de

Sterling SIHI GmbH
 Lindenstrasse 170

D-25524 Itzehoe
Germany
Tel: 048 21 771303
Fax: 048 21 771310
Email: vs.ltzehoe@sterlingsihi.de
Web: www.sterlingfluidsystems.de

Oswald Suck GmbH
Altstadtstrasse 1-5
D-99817 Eisenach
Germany
Tel: 03691 203250
Fax: 03691 732730
Email: pumpen-suck@t-online.de
Web: www.pumpen-suck.de

Teikoku Electric GmbH
Nürnberger Stasse 24
D-40599 Düsseldorf
Germany
Tel: 0211 700 6778
Fax: 0211 749 0011
Email: info@teikoku-electric.de
Web: www.teikokupump.de

Tsurumi (Europe) GmbH
Helforfer Strasse 16
D-40472 Düsseldorf
Germany
Tel: 0211 4179373
Fax: 0211 4791429
Email: sales@tsurumi-europe.com

Uraca Pumpenfabrik GmbH & Co KG
Sirchinger Strasse 15
D-72574 Bad Urach
Germany
Tel: 07125 1330
Fax: 07125 133202
Email: info@uraca.de
Web: www.uraca.de

Variopumps Pumpenbau GmbH
Carl-Zeiss Strasse 58
D-72770 Reutlingen
Germany
Tel: 07121 55573
Fax: 07121 503328
Email: info@variopumps.de
Web: www.variopumps.de

Victor Pumpen GmbH
Dieselstrasse 7
D-85551 Kirchheim bei München
Germany
Tel: 089 904 8660
Fax: 089 904 3447
Email: germany@victorpumps.com
Web: www.victorpumps.com

Willy Vogel AG
Motzener Strasse 35/37
D-12277 Berlin
Germany
Tel: 030 720 020
Fax: 030 720 0211
Email: info@vogel-berlin.de
Web: www.vogelag.com

Pumpenfabrik Wangen GmbH
Simoniusstrasse 17
D-88239 Wangen
Germany
Tel: 07522 9970
Fax: 07522 997199

Email: mail@wangen.com
Web: www.wangen.com

Wernert-Pumpen GmbH
Postfach 10 21 53
D-45421 Mülheim an der Ruhr
Germany
Tel: 0208 37580
Fax: 0208 407472
Email: info@wernert.de
Web: www.wernert.de

Wilo AG
Nortkirchenstrasse 100
D-44263 Dortmund
Germany
Tel: 0231 41020
Fax: 0231 4102 7575
Email: wilo@wilo.de
Web: www.wilo.de

Wilo EMU GmbH
Heimgartenstrasse 103
D-95030 Hof
Germany
Tel: 09281 9740
Fax: 09281 96528
Email: info@wiloemu.com
Web: www.emu.de

Wirth Group
Külner Strasse 71-73
D-41812 Erkelenz
Germany
Tel: 02431 830
Fax: 02431 83268
Email: info@wirth-europe.com
Web: www.wirth-europe.com

Witte Pumps & Technology GmbH
Esinger Steinweg 44a
D-25436 Uetersen
Germany
Tel: 04122 92870
Fax: 04122 928749
Email: info@witte-pumps.de
Web: www.witte-pumps.de

Woma Apparatebau GmbH
Werthausen Strasse 77-79
D-47226 Duisburg
Germany
Tel: 02065 3040
Fax: 02065 304200
Email: info@woma.de
Web: www.woma.de

Albert Ziegler GmbH & Co KG
Memminger Strasse 28
D-89537 Giengen/Brenz
Germany
Tel: 07322 951344
Fax: 07322 951464
Email: ziegler@ziegler.de
Web: www.ziegler.de

GREECE (GR)

ABS Hellas SA
1-3 Skra Street
Kallithea
GR-17372 Athens
Greece
Tel: 0210 9532501

Fax: 0210 9532504
Email: info@absgroup.com
Web: www.absgroup.com

Drakos-Polemis Inc
PO Box 51024
GR-145 10 Kifissia, Athens
Greece
Tel: 01 8161 402
Fax: 01 8161 262
Web: www.dppumps.gr

Korina Pumps
Kypriou Agoniston 51
Argyroupolis
GR-16451 Athens
Greece
Tel: 021 9910811
Fax: 021 9910811
Email: sales@korinapumps.gr
Web: www.korinapumps.gr

Rotex SA
Industrial Area
Sindos
GR-57022 Thessaloniki
Greece
Tel: 031 0797517
Fax: 031 0798510
Email: rotex-sa@the.forthnet.gr
Web: www.rotex.gr

HONG KONG (HK)

H & E Tsurumi Pump Co Ltd
Rm 1101, Chow Sang Sang Bldg
229 Nathan Road
Kowloon
Hong Kong
Tel: 27307208
Fax: 27306531
Email: info@tsurumi.com.hk

Tycon Alloy Industries (Hong Kong) Co Ltd
8/F, 22-28 Cheung Tat Road
Tsing Yi
New Territories
Hong Kong
Tel: 24499240
Fax: 24369872
Email: hongkong@tyconalloy.com
Web: www.tyconalloy.com

HUNGARY (HU)

ABS Hungary Trading
Kiss Ernő u 1-3
HU-1046 Budapest
Hungary
Tel: 01 231 6070
Fax: 01 231 6080
Email: info@absgroup.com
Web: www.absgroup.com

AxFlow Kft
Fő út 158
HU-2330 Dunaharaszti
Hungary
Tel: 024 460126
Fax: 024 462175
Email: axflow@axflow.hu
Web: www.axflow.hu

INDIA**(I)****Amrit Engineering Pvt Ltd**

2nd Floor, Motilal Centre, Near Dinesh Hall
Ashram Road, Ahmedabad
Gujarat 380 009
India

Tel: 079 658 3858**Fax:** 79 6580382**Email:** amrutpump@jindalonline.net**Best & Crompton Engineering Ltd**

28 Industrial Estate (North)
Ambattur
Chennai 600 098
Tamil Nadu
India

Tel: 044 6258782**Fax:** 044 6257059**Email:** bcmfg@net4india.com**Web:** www.bestcrompton.com**Calama Industries Pvt Ltd**

7 Gaiwadi Industrial Estate
SV Road, Goregaon W
Mumbai 400 062
India

Tel: 022 874 3563**Fax:** 022 874 3588**Email:** sales@calama.com**Web:** www.calama.com**Flowmore Private Ltd**

A-292, Mahipalpur Extension, N H - 8
East of Kailash
New Delhi 110037
India

Tel: 011 306 23740**Fax:** 011 267 83278**Email:** delmkt@flowmorepumps.com**Web:** www.flowmorepumps.com**Johnson Pump (India),
ATE Enterprises Ltd**

No A-19, CTS No 689, Veera Desai Road
Andheri (West)
Mumbai 400053
India

Tel: 022 634 6610**Fax:** 022 634 6609**Email:** ate_and@cateel.com**Jyoti Plastic Works Pvt Ltd**

94, B T Compound
Malad (West)
Mumbai 400064
India

Tel: 022 288 23241**Fax:** 022 288 20629**Email:** prashant@jyotimail.com**Web:** www.jyotioplastics.com**Kishor Pumps Ltd**

21 Barve Complex, 1170 / 1
J M Road, Shivaji Nagar
Pune 411005
India

Tel: 020 2551 1530**Fax:** 020 2553 9887**Email:** csd@kishorpumps.com**Web:** www.kishorpumps.com**Laxmi Hydraulics Pvt Ltd**

129-130 Industrial Estate, Patil Nagar, Hotgi
Road,

Solapur

Maharashtra 413003

India

Tel: 0217 2601763**Fax:** 0217 2601836**Email:** spr_lhpmotor@sancharnet.in**Web:** www.lhp.co.in**Leak-Proof Engineering (I) Pvt Ltd.**

F-1, Laxmi Industrial Estate
New Link Road, Andheri (W)
Mumbai 400053
India

Tel: 022 6361737**Fax:** 022 636 8429**Email:** leakprof@bom5.vsnl.net.in**Web:** www.leakproofseals.com**Mather & Platt Pumps Ltd**

Pune-Mumbai Road
Chinchwad
Pune 411019
India

Tel: 020 274 42100**Fax:** 020 274 42111**Email:** headoffice@pun.matherplatt.co.in**Web:** www.matherplatt.com**PPI Pumps Pvt Ltd**

14 & 16 E, Phase I
GIDC Estate Vartva
Ahmedabad 382445
India

Tel: 079 2583 2273**Fax:** 079 2583 0578**Email:** sales@prashant-ppi.com**Web:** www.prashant-ppi.com**PreciDose Pumps & Systems**

62/13, Phase I
Nr Patels Airtemp, GIDC Estate Vartva
Ahmedabad 382445
India

Tel: 079 5830762**Fax:** 079 5830762**Email:** sales@precidose.com**Web:** www.precidose.com**Process Pumps (India) Pvt Ltd**

86, III Phase
Peenya Industrial Area
Bangalore 560058
India

Tel: 080 839 5327**Fax:** 080 839 5807**Email:** contact@process-pumps.com**Web:** www.process-pumps.com**Pump Engineering Co Pvt Ltd**

C-38, 39
GIDC Estate Odhav
Ahmedabad 382410
India

Tel: 079 2871257**Fax:** 079 2874375**Email:** sdpatel@pecpumps.com**Web:** www.pecpumps.com**Raj Pumps**

9 Heavy Industrial Area
Jodhpur 342003
India

Tel: 0291 740937**Fax:** 0291 740905**Email:** rajpump@yahoo.com**Web:** www.rajpumps.com**Roto Pumps Ltd**

Roto House
Noida Special Economic Zone
Noida 201305 UP
India

Tel: 0120 2567677**Fax:** 0120 2562561**Email:** contact@rotopumps.com**Web:** www.rotopumps.com**Rotomac Industries Pvt Ltd**

D-4A, Panki Industrial Area
Site 1
Kanpur 208022
India

Tel: 0512 269 1704**Fax:** 0512 269 1706**Email:** rotmac@vsnl.net**Web:** www.rotomacpump.com**Sharp Trendys**

Sharp Nagar
Kalapatti
Coimbatore 641035
India

Tel: 0422 828631**Fax:** 0422 827632**Web:** www.sharptrendys.com**Swelore Engineering Pvt Ltd**

2109 Phase III GIDC Vatwa
Ahmedabad 382445
Gujarat
India

Tel: 079 583 3003**Fax:** 079 583 3337**Email:** swelore@ad1.vsnl.net.in**Web:** www.swelore.com**Titanium Tantalum Products Ltd**

86/1 Vengaivasal Main Road
Gowrivakkam
Chennai 601302
Tamil Nadu
India

Tel: 044 2278 1210**Fax:** 044 2375209**Email:** globalsales@titanindia.com**Web:** www.titanindia.com**Tuschaco Pumps Ltd**

401 Gulab
237 P D'Mello Road
Mumbai 400001
India

Tel: 022 262 0159**Fax:** 022 261 5458**Email:**

hointernational@tushacopumps.com

Web: www.tushacopumps.com**Ujala Pumps Pvt Ltd**

163 Patparganj Industrial Area
New Delhi 110092
India

Tel: 011 215 1421**Fax:** 011 222 7708**Email:** ujala@ndf.vsnl.net.in**Voltas Ltd**

Voltas House B
T B Kadam Marg

Mumbai 400033
India
Tel: 022 374 7995
Fax: 022 373 2330
Email: mramani@voltas.com
Web: www.voltas.com

Waterman Industries Ltd
3 Mira Co-Op Industrial Estate
Near Dahisar Check
Mumbai 401104
India
Tel: 022 811 2555
Fax: 022 811 1129
Web: www.indopumps.com

WPIL Ltd
22 Ferry Fund Road
Panihati
Kolkata 700114
West Bengal
India
Tel: 033 2553 1872
Fax: 033 2553 1276
Email: subrata@wpilltd.com
Web: www.wpil.com

INDONESIA

(ID)

PT Ebara Indonesia
JL Raya Jakarta-Bogor KM
32 Desa Curug
Jawa Barat
Indonesia
Tel: 021 874 0852
Fax: 021 874 0033
Web: www.ebara.co.jp

IRELAND

(IE)

ABS Pumps (Irl) Ltd
ABS House, Riverview Business Park
New Nangor Road
Dublin 12
Ireland
Tel: 01 460 8888
Fax: 01 460 8889
Email: info@absgroup.com
Web: www.absgroup.com

AxFlow Ltd
Dublin Industrial Estate, Unit 46
Barrow Road, Glasnevin
Dublin 11
Ireland
Tel: 018 300744
Fax: 018 300017
Email: info@axflow.ie
Web: www.axflow.ie

Flexachem Manufacturing Ltd
Donnybrook Commercial Centre
Douglas
Cork
Ireland
Tel: 021 363742
Fax: 021 891297
Email: sales@flexachem.com
Web: www.flexachem.com

ITALY

(IT)

ABS International Srl
Via Castellazzo 4

I-20040 Cambiago (MI)
Italy
Tel: 02 9506961
Fax: 02 95349203
Email: info@absgroup.com
Web: www.absgroup.com

ABS Italy Srl
Via Lavoro 87
I-40033 Casalecchio (BO)
Italy
Tel: 051 6169511
Fax: 051 6169582
Email: info@absgroup.com
Web: www.absgroup.com

Alma Pompe
Via dell'Artigianato 7
I-20090 Fizzonasco di Pieve
Emanuele (MI)
Italy
Tel: 02 90723657
Fax: 02 90420003
Email: sales@almapompe.it
Web: www.almapompe.it

Annovireverberi SpA
Via ML King 3
I-41100 Modena
Italy
Tel: 059 414411
Fax: 059 253505
Email: industria@annovireverberi.it
Web: www.annovireverberi.it

Argal Srl
Via Labirinto 159
I-25125 Brescia
Italy
Tel: 030 3507011
Fax: 030 3507077
Email: export@argal.it
Web: www.argal.it

Asco Pompe srl
Via Silvio Pellico 6/8
I-20089 Rozzano (MI)
Italy
Tel: 02 892571
Fax: 02 89257201
Email: asco@ascopompe.com
Web: www.ascopompe.com

Gruppo Aturia SpA
Piazza Aturia 9
I-20060 Gessate (MI)
Italy
Tel: 0295 423200
Fax: 0295 423202
Email: aturia@gruppoaturia.it
Web: www.gruppoaturia.com

AxFlow SpA
Via del Commercio
I-20090 Buccinasco (MI)
Italy
Tel: 02 48481
Fax: 02 48401926
Email: info@axflow.it
Web: www.axflow.it

Bizzi & Tedeschi Srl
Via Brodolini 35/A
I-42040 Campegine (RE)
Italy

Tel: 0522 677209
Fax: 0522 677633
Email: info@bizzi.it
Web: www.bizzi.it

Calpeda SpA
Via Roggia di Mezzo 39
I-36050 Montorso Vicentino -Vicenza
Italy
Tel: 0444 476476
Fax: 0444 476477
Email: export@calpeda.it
Web: www.calpeda.it

Caprari SpA
Via Emilia Ovest 900
I-41100 Modena
Italy
Tel: 059 897611
Fax: 059 897897
Email: info@caprari.it
Web: www.caprari.com

CDR Pompe SpA
Via Togliatti 26/A
I-20030 Senago (MI)
Italy
Tel: 02 9901941
Fax: 02 9980606
Email: info@cdrpompe.it
Web: www.cdrpumps.com

DAB Pumps SpA
Via Marco Polo 14
I-35035 Mestrino (PD)
Italy
Tel: 049 9048811
Fax: 049 9048847
Email: info@dabpumps.com
Web: www.dabpumps.com

DDA Srl
Via Silvio Pellico 6/8
I-20089 Rozzano (MI)
Italy
Tel: 02 89257257
Fax: 02 89257241
Email: dpulici@ddasrl.com
Web: www.dda.it

Debem
Via Del Bosco 41
I-21052 Busto Arsizio (VA)
Italy
Tel: 03 31074034
Fax: 03 31074036
Email: info@debem.it
Web: www.debem.it

Dragflow Srl
Via Spagna 13
I-37069 Villafranca-Verona
Italy
Tel: 045 6304521
Fax: 045 6335758
Email: dragflow@sovema.it
Web: www.dragflow.it

Ebara Pumps Europe SpA
Via Pacinotti 32
I-36040 Brendola (Vicenza)
Italy
Tel: 0444 706811
Fax: 0444 706950

Email: marketing@ebaraeurope.com
Web: www.ebaraeurope.com

Finder Pompe SpA

Via Bergamo 65
 I-23807 Merate (LC)
 Italy
Tel: 039 99821
Fax: 039 599267
Email: finder@finderpompe.com
Web: www.finderpompe.com

GMP SpA

Via Sale 119-121
 I- 25064 Gussago (BS)
 Italy
Tel: 030 2775411
Fax: 030 2772418
Web: www.gmpumps.com

Grundfos Pompe Italia Srl

Via Gran Sasso 4
 I-20060 Truccazzano (MI)
 Italy
Tel: 0295 838112
Email: ffederico@grundfos.com
Web: www.grundfos.com

Imovilli Pompe Srl

Via Masaccio 1 (Z I Mancasale)
 I-42100 Reggio Emilia
 Italy
Tel: 0522 516595
Fax: 0522 514735
Email: info@imovillipompe.it
Web: www.imovillipompe.it

Interpump Group SpA

Via E. Fermi 25
 I-42040 Calerno di S. Ilario d'Enza (RE)
 Italy
Tel: 0522-904311
Fax: 0522-904444
E-mail: info@interpumpgroup.it
Web: www.interpumpgroup.it

Jurop SpA

Via Crosera 50 Azzano Decimo
 I-33082 Pordenone
 Italy
Tel: 0434 636811
Fax: 0434 636812
Email: jurop@jurop.it
Web: www.jurop.it

Landini Fabbrica Pompe Centrifughe Srl

Viale Dante 4
 I-46023 Gonzaga MN
 Italy
Tel: 0376 588222
Fax: 0376 58140
Email: info@landini.net
Web: www.landini.net

Larius Srl

Via Stoppani 21
 I-23801 Calolziocorte Lecco
 Italy
Tel: 0341 621152
Fax: 0341 621243
Email: larius@larius.com
Web: www.larius.com

Liverani Srl

Via De' Brozzi 94/3

I-48022 Lugo (RA)

Italy
Tel: 0545 22379
Fax: 0545 30350
Email: liverani@liverani.com
Web: www.liverani.com

Lowara SpA, ITT Industries

I-36075 Montebellio Maggiore (VI)
 Italy
Tel: 0444 707111
Fax: 0444 492166
Email: mkt@lowara.ittind.com
Web: www.lowara.com

Matra SpA

Via Papa Giovanni XXIII 33
 I-41100 Modena
 Italy
Tel: 059 250407
Fax: 059 251548
Email: info@matra.it
Web: www.matra.it

Nuovo Pignone

Via Felice Matteucci 2
 I-50127 Florence
 Italy
Tel: 055 4272500
Web: www.gepower.com

OFT (Officine Di Trevi)

SS Flaminia km 145
 I-06032 Borgo di Trevi (Perugia)
 Italy
Tel: 0742 381616
Fax: 0742 78792
Email: oft@officineditrevi.com
Web: www.officineditrevi.com

Omac Srl

Via G Falcone 8
 I-42048 Rubiera (RE)
 Italy
Tel: 0522 629371
Fax: 0522 628980
Email: info@omacpompe.com
Web: www.omacpompe.com

Pedrollo SpA

Via E Fermi 75
 I-37047 Bonifacio (VA)
 Italy
Tel: 045 6136311
Fax: 045 7614663
Email: pedrollo@pedrollo.com
Web: www.pedrollo.com

Pentair Pumps SpA

Via Masaccio 13
 I-56010 Lugnano (PI)
 Italy
Tel: 050 716111
Fax: 050 703137
Email: pentairpumps@pw-europe.com
Web: www.pentairpumps.it

Peroni Pompe SpA

Via Forze Armate 310/5
 I-20152 Milan
 Italy
Tel: 02 489401
Fax: 02 48910287
Email: marketing@peronipompe.it
Web: www.peronipompe.com

Pompe Cucchi Srl

Via dei Pioppi 39
 I-20090 Opera (MI)
 Italy
Tel: 02 57606287
Fax: 02 57602257
Email: sales@pompecucchi.it
Web: www.pompecucchi.it

Pompe Garbarino SpA

Via Marengo 44
 I-15011 Acqui Terme (AL)
 Italy
Tel: 0144 388671
Fax: 0144 55260
Email: info@pompegarbarino.com
Web: www.pompegarbarino.com

Ragazzini Srl

Via Volta 8
 I-48018 Faenza (RA)
 Italy
Tel: 0546 620433
Fax: 0546 621394
Email: ragazzinipompe@linknet.it
Web: www.ragazzini.it

Rovatti Pompe

Via Trento 22/24
 I-42042 Fabbrico RE
 Italy
Tel: 0522 665000
Fax: 0522 665020
Email: info@rovatti.it
Web: www.rovatti.it

Sacem SpA

Via Valsugana 19
 I-35010 San Giorgio in Bosco (Padova)
 Italy
Tel: 049 9450022
Fax: 049 9450044
Email: sacem@sacem.it
Web: www.sacem.it

Saer Elettropompe

Via Circonvallazione 22
 I-42016 Guastalla (RE)
 Italy
Tel: 0522 830941
Fax: 0522 826948
Email: info@saerelettropompe.com
Web: www.saerelettropompe.com

Salmson Italia

Via Jacopo Peri 80
 I-41100 Modena
 Italy
Tel: 059 280380
Fax: 059 282331
Email: salmson@salmson.it
Web: www.salmson.it

Savino Barbera

Via Torino 12
 I-10032 Brandizzo (TO)
 Italy
Tel: 011 9139063
Fax: 011 9137313
Email: info@savinobarbera.com
Web: www.savinobarbera.com

Seko Bono Exacta SpA

Via Salaria
 KM 92 200

I-02010 S Rufina Rieti
Italy
Tel: 0746 605801
Fax: 0746 607072
Email: sales@seko.com
Web: www.seko.com

Simaco Elettromeccanica Srl
16 Strada Statale 235
I-26834 Cadilana-Corte Palasio (LO)
Italy
Tel: 0371 59181
Fax: 0371 420566
Email: info@simacosrl.it
Web: www.simacosrl.it

Sterling Fluid Systems (Italy) SpA
Via Pompei 15
I-20052 Monza
Italy
Tel: 039 28241
Fax: 039 2824220
Email: sterlingitaly@sidro.it
Web: www.sterlingfluid.com

Subteck Srl
Via Ragazzi 99
34 ZI Mancasale
I-42100 Reggio Emilia
Italy
Tel: 0522 921160
Fax: 0522 921178
Email: info@subteck.it
Web: www.subteck.it

Sumoto Srl
Via Peripoli R e G 1/3
I-36041 Alte Montecchio Maggiore (VI)
Italy
Tel: 0444 490515
Fax: 0444 490518
Email: info@sumoto.com
Web: www.sumoto.com

Termomeccanica Pompe SpA
via Del Molo 3
I-19126 La Spezia (SP)
Italy
Tel: 0187 552512
Fax: 0187 552506
Email: pumps@termomeccanica.com
Web: www.tmp.termomeccanica.com

Tesla Srl
Via Del Lavoro 3
I-36040 San Germano Dei Berici (VI)
Italy
Tel: 0444 868099
Fax: 0444 868211
Email: info@teslasub.it
Web: www.teslasub.it

Varisco Srl
Zona Ind Nord
Terza Strada 9
I-35129 Padova
Italy
Tel: 049 8294111
Fax: 049 8076762
Email: info@variscopompe.com
Web: www.variscopspa.com

Pompe Vergani
Via Bergamo 65

I-23807 Merate (LC)
Italy
Tel: 039 99821
Fax: 039 599267
Email: finder@finderpompe.com
Web: www.pompevergani.com

Weir Gabbioneta Srl
Viale Cariraghi 68
I-20099 Sesto San Giovanni (MI)
Italy
Tel: 02 2241001
Fax: 02 2424550
Email: sales@pompegabbioneta.com
Web: www.pompegabbioneta.com

Worthington SpA
Flowserve Corporation, Pump Division
Via Rossini 90/92
I-20033 Desio (Milan)
Italy
Tel: 0362 6121
Fax: 0362 303396
Email: mrestelli@flowserve.com
Web: www.flowserve.com

JAPAN

(JP)

Ebara Corporation
11-1 Haneda Asahi-cho
Ohta-ku
Tokyo 144-8510
Japan
Tel: 05714 6111
Fax: 03745 3356
Email: pump@ebara.co.jp
Web: www.ebara.co.jp

Grundfos Pumps KK
Gotanda Metalion Bldg 5F
5-21-15, Higashi-gotanda
Shiagawa-ku
Tokyo 141-0022
Japan
Tel: 03 5448 1391
Email: info-gjk@grundfos.com
Web: www.grundfos.com

Honda Kiko Co Ltd
2055 Yamano Inatsuki-Cho
Kaho-gun
Fukuoka 820-0202
Japan
Tel: 0948 42 3111
Fax: 0948 42 3118
Email: info@hondakiko.co.jp
Web: www.hondakiko.co.jp

Iwaki Co Ltd
2-6-6 Kanda Sudacho Chiyoda-ku
Tokyo 101-8558
Japan
Tel: 03 3254 2935
Fax: 03 3252 8892
Email: info@iwakipumps.jp
Web: www.iwakipump.jp

Kawamoto Pump Manufacturing Co Ltd
11-39, Ohsu 4-Chome
Naka-ku
Nagoya 460-8650
Japan
Tel: 052 251 7171
Fax: 052 241 6151

Email: kawamototr@aol.com
Web: www.kawamoto.co.jp

Kubota Corporation
3-1-3 Nihonbashi-muromachi
Chuo-ku,
Tokyo 103-8310
Japan
Tel: 03 3245 3111
Fax: 03 3245 3049
Email: pump@kubota.co.jp
Web: www.kubota.co.jp

Mazda Pump Manufacturing Co Ltd
6-14, Nogami 2-chome
Takarazuka-shi
Hyogo 665-0022
Japan
Tel: 0797 71 8585
Fax: 0797 71 8039
Email: matsuda@mazdapump.co.jp
Web: www.mazdapump.co.jp

Nikkiso Co Ltd
3-43-2 Ebisu
Shibuya-ku
Tokyo 150-8677
Japan
Tel: 03 3443 3711
Fax: 03 3444 4963
Web: www.nikkiso.co.jp

Sakuragawa Pump Manufacturing Co Ltd
1-2-11 Itsukaichi
Ibaraki
Osaka
Japan
Tel: 072 645 5254
Fax: 072 645 5253
Email: pr@sakura-p.net
Web: www.sakura-p.net

Taiko Kikai Industries Co Ltd
MS Building 4th Floor, Suidobashi
3-4-9, Misaki-cho, Chiyoda-ku
Tokyo 101-0061
Japan
Tel: 03 3221 8551
Fax: 03 3221 8555
Email: tokyo-br@taiko-kk.com
Web: www.taiko-kk.com

Torishima Pump Mfg Co Ltd
1-1-8 Miyata-cho
Takatsuki City
Osaka 569-8600
Japan
Tel: 072 695 0551
Fax: 072 693 1288
Web: www.torishima.co.jp

Tsurumi Manufacturing Co Ltd
16-40 4-chome, Tsurumi
Tsurumi-ku
Osaka 538-8585
Japan
Tel: 06 6911 7271
Fax: 06 6911 0100
Email: intsales@tsurumipump.co.jp
Web: www.tsurumipump.co.jp

Yamada Corporation
1-3, 1-chome Minamimagome
Ota-ku

Tokyo 143-8504
Japan
Tel: 03 3777 0241
Fax: 03 3777 0584
Email: intl@yamadacorp.co.jp
Web: www.yamadacorp.co.jp

MALASIA (MY)

ABS Pumps Malaysia Sdn Bhd
No 27 Jalan Tambur 33/19
Shah Alam Technology Park, Seksyen 33
MY-40400 Shah Alam Selangor Darul
Ahsan
Malaysia
Tel: 03 5124 6550
Fax: 03 5124 6548
Email: info@absgroup.com
Web: www.absgroup.com

Tsurumi Pump (Malaysia) SDN BHD
22 Jalan PJU 3/41, Sunway Damansara
47810 Petaling Jaya
Selangor
Malaysia
Tel: 03 7803 3373
Fax: 03 7806 3748
Email: tsurumi@tm.net.my

MEXICO (MX)

Corporacion EG SA
Av San Jerónimo 514-A
Monterrey
NL 64640
Mexico
Tel: 083 81 0064
Fax: 083 81 0212
Email: wdm@corporacioneg.com
Web: www.corporacioneg.com

THE NETHERLANDS (NL)

ABS Pompen BV
Kaarvelweg 9
Postbus 120
6200 AC Maastricht
The Netherlands
Tel: 043 352 5050
Fax: 043 363 3395
Email: info@absgroup.com
Web: www.absgroup.com

ABS Pompen BV
Kobaltweg 27
Postbus 120
3542 CE Utrecht
The Netherlands
Tel: 030 242 5678
Fax: 030 241 0346
Email: info@absgroup.com
Web: www.absgroup.com

AxFlow BeNeLux BV
PO Box 50110
1305 AC Almere
The Netherlands
Tel: 036 538 1211
Fax: 036 531 1725
Email: axflow@axflow.nl
Web: www.axflow.nl

Bredel Hose Pumps
PO Box 47

7400 AA Delden
The Netherlands
Tel: 074 377 0000
Fax: 074 376 1175
Email: hosepumps@bredel.com
Web: www.bredel.com

DP-Pumps
PO Box 28
2400 AA Alphen aan den Rijn
The Netherlands
Tel: 0172 488325
Fax: 0172 468930
Email: dp@dp-pumps.com
Web: www.dp-pumps.com

Houttuin Holland BV
Sophialaan 4
3542 AB Utrecht
The Netherlands
Tel: 030 248 4611
Fax: 030 241 1845
Email: saleshouttuin@colfaxpump.com
Web: www.houttuin.nl

Johnson Pump BV
Dr AF Philipsweg 51
PO Box 9
9400 AA Assen
The Netherlands
Tel: 0592 376767
Fax: 0592 376760
Email: export.nl@johnson-pump.com
Web: www.johnson-pump.com

Melotte Pumptechnology BV
Fregatweg 50
6222 NZ Maastricht
The Netherlands
Tel: 043 368 4141
Fax: 043 363 7446
Email: info@pumptech.nl
Web: www.pumptech.nl

Nijhuis Pompen BV
PO Box 102
7100 DE Winterswijk
The Netherlands
Tel: 0543 547474
Fax: 0543 547475
Email: nijhuis@nijhuispompen.nl
Web: www.nijhuispompen.nl

Pomac Industries Group
PO Box 32
9356 ZG Tolbert
The Netherlands
Tel: 0594 512877
Fax: 0594 517002
Email: sales@pomac.nl
Web: www.pomac.nl

Robot Pumps BV
PO Box 140
2400 AC Alphen a/d Rijn
The Netherlands
Tel: 0172 418 686
Fax: 0172 418 602
Email: info@robotpumps.com
Web: www.robot-pumps.com

Spaans Babcock BV
PO Box 79
8560 AB Balk
The Netherlands

Tel: 0514 608 282
Fax: 0514 604 485
Email: sales@spaansbabcock.nl
Web: www.spaansbabcock.com

Sterling Fluid Systems (Netherlands)
Havenstraat 22-28
1948 NP Beverwijk
The Netherlands
Tel: 0251 263232
Fax: 0251 226309
Email: info@sihi.nl
Web: www.sterlingfluid.com

Verder Group
Utrechtseweg 4a
3451 GG Vleuten
The Netherlands
Tel: 091 306 779211
Fax: 091 306 771402
Email: info@verder.nl
Web: www.verder.com

Yamada Europe BV
Aquamarijnstraat 50
7554 NS Hengelo
The Netherlands
Tel: 074 242 2032
Fax: 074 242 1055
Email: company@yamada.nl
Web: www.yamada.nl

NEW ZEALAND (NZ)

Macquarrie Corporation
1620 Hume Highway
Campbellfield
VIC 3061
New Zealand
Tel: 03 9358 5555
Fax: 03 9358 5556
Email: macquarrie@macquarrie.com.au
Web: www.macquarrie.com.au

Mono Pumps (New Zealand) Ltd
PO Box 71-021
35-41 Fremelin Place, Avondale
Auckland 7
New Zealand
Tel: 09 8290333
Email: info@mono-pumps.co.nz
Web: www.mono-pumps.com

NIGERIA (NG)

Cakasa (Nigeria) Co Ltd
PO Box 871, 96 Palm Avenue
Mushin
Lagos
Nigeria
Tel: 01 452 2955
Fax: 01 452 2887
Email: cnchq@cakasa.com
Web: www.cakasa.com

NORWAY (NO)

ABS Oumoer A/S
Industriveien 40
Postboks 473
N-1302 Sandvika
Norway
Tel: 067554700

Fax: 067554750
Email: info@absgroup.com
Web: www.absgroup.com

Aker Kvaerner Eureka Pump Systems
 PO Box 94
 N-1325 Lysaker
 Norway
Tel: 067826000
Fax: 067826400
Email: kjell.bamberg@akerkvaerner.com
Web: www.kvaerner.com

AxFlow AS
 PO Box 98
 Lillaker
 N-0216 Oslo
 Norway
Tel: 022736700
Fax: 022736786
Email: axflow@axflow.no
Web: www.axflow.no

Framo Engineering AS
 PO Box 174, Sandsli
 N-5862 Bergen
 Norway
Tel: 055928800
Fax: 055928900
Email: sales@framoeng.no
Web: www.framoeng.no

Frank Mohn AS
 PO Box 98
 Slåtthaug
 N-5851 Bergen
 Norway
Tel: 055999000
Fax: 055999380
Email: marine@framo.no
Web: www.framo.no

POLAND

(PL)

ABS Polska Sp. Z.o.o.
 Ul Rydygiera 8
 Budynek A
 PL-01-793 Warsaw
 Poland
Tel: 022 633 8287
Fax: 022 633 8644
Email: info@absgroup.com
Web: www.absgroup.com

AxFlow Sp Soo
 ul. Floriana 3/5
 PL-04-664 Warsaw
 Poland
Tel: 022 613 0012
Fax: 022 812 1327
Email: biuro@axflow.pl
Web: www.axflow.pl

Gzut SA Pumps Department
 ul Robotnicza 2
 PL-44-100 Gliwice
 Poland
Tel: 032 338 1510
Fax: 032 231 6908
Email: market@gzut.com.pl
Web: www.gzut.com.pl

Kielecka Fabryka Pomp Bialogon SA
 ul Druckiego

Lubeckiego 1
 PL-25-818 Kielce
 Poland
Tel: 041 366 8219
Fax: 041 345 5154
Email: handel@kfp-bialogon.com.pl
Web: www.kfp-bialogon.com.pl

Leszno Pump Factory
 ul Fabryczna 15
 PL-64-100 Leszno
 Poland
Tel: 065 528 8700
Fax: 065 529 9246
Email: lfp@lfp.com.pl
Web: www.lfp.com.pl

Metalchem-Warszawa SA
 Studzienna 7a
 PL-01-259 Warsaw
 Poland
Tel: 022 837 1270
Fax: 022 36 8950
Email: metalchem@elektron.pl
Web: www.metalchemsa.com.pl

Powen Pump Factory Co Ltd
 ul Wolnosci 318
 PL-41-800 Zabrze
 Poland
Tel: 032 777 5777
Email: pompy@powen.com.pl
Web: www.powen.com.pl

Swidnicka Fabryka Pomp Sp Z.o.o.
 Inzynierska 8
 PL-58-100 Swidnica ul
 Poland
Tel: 074 851 8100
Fax: 074 853 3357
Email: marketing@sfpomp.com.pl
Web: www.sfpomp.com.pl

Wafapomp SA
 ul Odelwnicza 1
 PL-03 231 Warsaw
 Poland
Tel: 022 811 1431
Fax: 022 811 3146
Email: biuro@wafapomp.com.pl
Web: www.wafapomp.com.pl

PORTUGAL

(PL)

ABS Hidrobomba SA
 Rua Antonio Maia 6-A
 Apartado 60120
 P-2720-902 Amadora
 Portugal
Tel: 021 495 0157
Fax: 021 495 5364
Email: info@absgroup.com
Web: www.absgroup.com

AxFlow Ida
 Av Duarte Pacheco 2, Apartado 92
 Sto Amaro de Oeiras
 P-2780-316 Oeiras
 Portugal
Tel: 021 446 1590
Fax: 021 441 0368
Email: axflow@axflow.pt
Web: www.axflow.pt

RUSSIA

(RU)

PCM Pompes Russia
 nab kanala Griboedova, d.15, 18H
 liter A, (No 8)
 191186 Saint Petersburg
 Russia
Tel: 0812 320 7096
Fax: 0812 320 7512
Email: pcmrussia@pcmpompes.com
Web: www.pcmpompes.com

SINGAPORE

(SG)

ABS Wastewater Technology Pte Ltd
 25 International Business Park
 #03-51/55 German Centre
 Singapore 609 916
 Singapore
Tel: 06 4633933
Fax: 06 4622122
Email: info@absgroup.com
Web: www.absgroup.com

Tsurumi (Singapore) Pte Ltd
 26 Hillview Terrace
 Singapore 669237
 Singapore
Tel: 06 7608338
Fax: 06 7601268
Email: sales@tsurumipump.com.sg

Grundfos (Singapore) Pte Ltd
 24 Tuas West Road
 Singapore 638381
 Singapore
Tel: 06 8651222
Email: contact-sg@grundfos.com
Web: www.grundfos.com

SLOVAKIA

(SK)

Slovpump-Trade Sro
 Osloboditel'ov 4
 SK-976 67 Závadka nad Hronom
 Slovakia
Tel: 048 618 3384
Fax: 048 618 3386
Email: obchod@slovpump.sk
Web: www.slovpump.sk

SOUTH AFRICA

(ZA)

ABS Wastewater Technology (Pty) Ltd
 Unit 2, Cnr Innes and Bismut Roads
 Jetpark Boksburg
 Edleen 1625
 South Africa
Email: info@absgroup.com
Web: www.absgroup.com

Denorco (Pty) Ltd
 PO Box 8136
 Edenglen 1613
 South Africa
Tel: 011 609 4150
Fax: 011 609 2417
Email: richardr@denorco.com
Web: www.denorco.com

Rapid Allweiler Pump & Engineering
 PO Box 73
 Isando 1600
 South Africa

Tel: 011 573 7400
Fax: 011 974 8977
Email: solution@rapidpumps.co.za
Web: www.rapidpumps.co.za

Rhine Ruhr Pumps & Valves (Pty) Ltd
 PO Box 76167
 Wendywood
 Johannesburg 2144
 South Africa
Tel: 011 444 1321
Fax: 011 444 3373
Email: info@rrpumps.co.za
Web: www.rrpumps.co.za

CH Warman Pump Group
 PO Box 3607
 Kempton Park 1620
 South Africa
Tel: 011 908 6601
Fax: 011 908 5636
Email: pumpsales@warman.co.za
Web: www.warman.co.za

SOUTH KOREA (KR)

A-Ryung Machinery Ind Co Ltd
 681-1 Daegok-Ri, Keumseong-Myun
 Damyang-Gun
 Cheonnam 517-810
 South Korea
Tel: 068 4382 4401
Fax: 068 4382 3094
Email: aryung@aryung.co.kr
Web: www.aryung.co.kr

Chung Woo Industrial Co Ltd
 682-14, Kyongso-Dong
 So-Ku
 Incheon
 South Korea
Tel: 032 561 0971
Fax: 032 566 0972
Email: chungwoo@chwpump.co.kr
Web: www.cwhydro.co.kr

Handol Pumps Ltd
 428-10 Nonhyun-Dong
 Namdong-Gu
 Incheon 405-848
 South Korea
Tel: 032 818 0105
Fax: 032 818 0109
Email: hdpump@unitel.co.kr
Web: www.hdpump.co.kr

Hyosung-Ebara Co Ltd
 6th floor Hyosung Building
 450 Kongduk-Dong
 Mapo-Ku
 Seoul 121-120
 South Korea
Tel: 02 707 6395
Fax: 02 711 5501
Email: hec-shhong@hyosung.com
Web: www.hyosungebara.com

Ilsung Precision Industry Company
 1619-3 Bisan 7 Dong Suhgu
 Taegu-City 703-047
 South Korea
Tel: 053 358 9234
Fax: 053 353 0946

Email: ipco@hitel.net
Web: ipco.koreasme.com

Shin Shin Machinery Co Ltd
 940-13 Yealim-Li
 Jungghwan-Myum, Gijang-Gun
 Busan 619-731
 South Korea
Tel: 051 727 53004
Fax: 051 727 5305
Email: leeyk@www.sspump.com
Web: www.sspump.com

SPAIN (ES)

ABS Tecnologías del Agua SA
 C/Madera 14-16, Pol Ind Sanat Ana
 Urb Rivas-Vaciamadrid
 E-28529 Madrid
 Spain
Tel: 091 670 2851
Fax: 091 666 5869
Email: info@absgroup.com
Web: www.absgroup.com

AxFlow SAS
 C/Antonio de Cabezón 83
 E-280 34 Madrid
 Spain
Tel: 091 729 1818
Fax: 091 729 2491
Email: axflow@axflow.es
Web: www.axflow.es

Bombas Boyser SL
 C/Empordà
 3 Poligono Industrial La Borda
 E-08140 Caldes De Montbui
 Spain
Tel: 093 865 5455
Fax: 093 865 5556
Email: bombas@boyser.com
Web: www.boyser.com

Casals Cardona Industries SA
 F Casablanas 24
 E-08243 Manresa
 Spain
Tel: 0902 443 000
Fax: 0938 757 668
Email: tecnum@tecnum.es
Web: www.tecnum.com.cn

Ebara España Bombas SA
 PI La Estación, C/ Cormoranes, 6
 E-28320 Pinto (Madrid)
 Spain
Tel: 916 923 630
Fax: 916 923 891
Email: marketing@ebara.es
Web: www.ebara.es

Hidráulicas HMT SA
 Pol Ind del Ramassá
 C/ Barcelonés, 14-16
 E-08520 Les Franqueses del Vallés -
 Barcelona
 Spain
Tel: 093 849 3822
Fax: 093 849 9066

Hidrotecar SA
 PO Box 281
 E-09080 Burgos
 Spain

Tel: 0947 48 4400
Fax: 0947 48 4557
Email: htecar@las.es
Web: www.hidrotecar.com

Inoxpa SA
 C/Telers 54
 PO Box 174
 E-17820 Banyoles (Girona)
 Spain
Tel: 0972 575200
Fax: 0972 575502
Email: inoxpa@inoxpa.com
Web: www.inoxpa.com

Bombas Itur SA
 PO Box 41, Urteta Bidea s/n
 E-20800 Zarautz (Gipuzkoa)
 Spain
Tel: 0943 899 899
Fax: 0943 130 170
Email: comexp@itur.es
Web: www.itur.es

Motorrens SL
 Pol Ind Mas de les Ànimes
 C / Apel les Mestres, 36-38
 E-43205 Reus
 Spain
Tel: 0977 328105
Fax: 0977 326552
Email: motorrens@rostor.com
Web: www.rostor.com

Bombas Omega SL
 Pol Ind El Campillo-Pab B
 E-48500 Abanto
 Spain
Tel: 094 6363510
Fax: 094 6363501
Email: bombas01@bombasomega.com
Web: www.bombasomega.com

Pedro Roquet SA
 Antonio Figueres 91
 E-08551 Tona (Barcelona)
 Spain
Tel: 093 812 4664
Fax: 093 887 1798
Email: roquet@pedro-roquet.com
Web: www.pedro-moquet.com

SWEDEN (SE)

ABS Group
 PO Box 394
 Roskildevägen 1
 SE-201 23 Malmö
 Sweden
Tel: 040 350470
Fax: 040 305045
Email: info@absgroup.com
Web: www.absgroup.com

Alfa Laval AB
 PO Box 73
 SE-221 00 Lund
 Sweden
Tel: 046 367000
Fax: 046 306860
Web: www.alfalaval.com

AxFlow AB
 Byängsgränd 14

PO Box 90162
SE-120 22 Stockholm
Sweden
Tel: 08 6022200
Fax: 08 916666
Email: kundservice@axflow.se
Web: www.axflow.se

Axflow Holding AB
Wennergren Center
Sveavägen 166, Floor 14
SE-113 46 Stockholm
Sweden
Tel: 08 54547670
Fax: 08 54547689
Email: axflow@axflow.com
Web: www.axflow.com

Grindex AB
Hantverkavägen 24, Box 535
SE-136 25 Haninge
Sweden
Tel: 08 6066600
Fax: 08 7455328
Email: info@grindex.com
Web: www.grindex.com

ITT Flygt AB
Gesällvägen 33
SE-174 87 Sundbyberg
Sweden
Tel: 08 4756000
Fax: 08 4756900
Email: ylva.ponsonby@flygt.com
Web: www.flygt.com

Johnson Pump AB
Nastagatan 19
PO Box 1436
SE-701 14 Örebro
Sweden
Tel: 019 218300
Fax: 019 272330
Email: jp@johnson-pump.com
Web: www.johnson-pump.com

Metso Minerals (Sala) AB
PO Box 302
SE-733 25 Sala
Sweden
Tel: 0224 57000
Fax: 0224 16950
Email: jan.lidin@mestso.com
Web: www.metsominerals.com/pumps

Pumpex Sales
PO Box 5207
SE-121 18 Johanneshov
Sweden
Tel: 08 725 4930
Fax: 08 659 3314
Email: info@pumpex.com
Web: www.pumpex.com

Tapflo AB
Filaregatan 4
SE-442 34 Kungälv
Sweden
Tel: 0303 63390
Fax: 0303 19916
Email: sales@tapflo.com
Web: www.tapflo.com

Imo AB
PO Box 42090

SE-126 14 Stockholm
Sweden
Tel: 08 50622800
Fax: 08 6451509
Email: sales@imo.se
Web: www.imopump.com

SWITZERLAND

AxFlow GmbH
Neumattweg 6
CH-5012 Schönenwerd
Switzerland
Tel: 062 849 6164
Fax: 062 849 6165
Email: axflow@bluewin.ch
Web: www.axflow.ch

Biral AG
Südstrasse 10
CH-3110 Münsingen
Switzerland
Tel: 031 720 9000
Fax: 031 720 9442
Email: info@biral.ch
Web: www.biral.ch

Catag AG
Auf dem Wolf 19
CH-4052 Basel
Switzerland
Tel: 061 373 7373
Fax: 061 373 7370
Email: catag@catag.com
Web: www.catag.com

CP Pumpen AG
Industrie Brühl
CH-4800 Zofingen
Switzerland
Tel: 062 746 8585
Fax: 062 746 8586
Email: schlueniger@cp-pumps.com
Web: www.cp-pumps.com

Emile Egger et Cie SA
CH-2088 Cressier/NE
Switzerland
Tel: 032 758 7111
Fax: 032 757 2290
Email: info@eggerpumps.com
Web: www.eggerpumps.com

Gotec SA
Rue des Casernes 59
CH-1950 Sion
Switzerland
Tel: 027 205 7205
Fax: 027 205 7206
Email: sales@gotec.ch
Web: www.gotec.ch

Gysi Pumpen AG
In Riaux
CH-1726 Farvagny
Switzerland
Tel: 026 411 3071
Fax: 026 411 3080
Email: info@gysi-pumpen.ch
Web: www.gysi-pumpen.ch

Häny AG
Bergstrasse 103

(CH)

CH-8706 Meilen
Switzerland
Tel: 01 925 4111
Fax: 01 923 6245
Email: info@haeny.com
Web: www.haeny.com

Ismatec SA
Feldeggstrasse 6
CH-8152 Glattbrugg
Switzerland
Tel: 01 874 9418
Fax: 01 810 5292
Email: taltham@idexcorp.com
Web: www.ismatec.com

Maag Pump Systems Textron AG
Aspstrasse 12
CH-8154 Oberglatt
Switzerland
Tel: 044 278 8200
Fax: 044 278 8201
Email: welcome@maag.textron.com
Web: www.maag.com

Rütschi Fluid AG
Herzogstrasse 11
CH-5200 Brugg
Switzerland
Tel: 056 441 0455
Fax: 056 441 1331
Email: info@rutschifluid.ch
Web: www.rutschipumpen.ch

SAWA Pumpentechnik AG
CH-9113 Degersheim
Switzerland
Tel: 071 372 0808
Fax: 071 372 0809
Email: info@sawa.ch
Web: www.sawa.ch

Scheerle AG
Frauenfelderstrasse 47b
CH-8266 Steckborn
Switzerland
Tel: 052 762 2221
Fax: 052 762 2266
Email: mail@scheerle.ch
Web: www.scheerle.ch

Sterling Fluid Systems (Schweiz) AG
Schweizersbildstrasse 25
CH-8205 Schaffhausen
Switzerland
Tel: 052 644 0606
Fax: 052 644 0616
Email: info@sterlingfluid.ch
Web: www.sterlingfluid.com

Sulzer Pumps
Zürcherstrasse 12
CH-8401 Winterthur
Switzerland
Tel: 052 262 1155
Fax: 052 262 0040
Email: info.pumps@sulzer.com
Web: www.sulzerpumps.com

3S Systemtechnik AG
Brunnmattstrasse 456
CH-5236 Remigen
Switzerland
Tel: 056 297 8888
Fax: 056 297 8880

Email: info@mariner-3s.com
Web: www.mariner-3s.com

TAIWAN (TW)

HCP Pump Manufacturer Co Ltd
 7 Kung Yeh 4th Road
 Ping Tung Industrial Zone
 Taipei Hsien
 Taiwan
Tel: 08 7229267
Fax: 08 7239119
Email: hcppump@ms7.hinet.net
Web: www.hcppump.com.tw

Hung Pump Industrial Co Ltd
 8F, No 251, San Ming Road
 Lu-Chou City
 Taipei Hsien
 Taiwan
Tel: 02 28472419
Fax: 02 28471559
Email: hungpump@ms9.hinet.net

Tsurumi Pump Taiwan Co Ltd
 67 Fengtian Street
 Bade City
 Tao-yuan 334
 Taiwan
Tel: 03 3689830
Fax: 03 3689832
Email: sales@tsurumipump.com.tw

THAILAND (TH)

ABS Nopon Thai Co Ltd
 60/9 Moo 3, Tabol Mabyangporn
 Amphur Pluakdang
 Rayong 21140
 Thailand
Tel: 038 891483
Fax: 038 891122
Email: info@absgroup.com
Web: www.absgroup.com

PCM Pompes Thailand
 171/16 Moo5 Salaya-Bangphasi Road
 Salaya, Budhamontol
 Nakornpathom 73170
 Thailand
Tel: 034 246012
Fax: 034 297022

TUNISIA (TN)

PCM Tunisia
 Bureau d'Assistance Technique
 Imm L, Appt 6
 Cité Essaada, El Menzah 7
 2037 Ariana
 Tunisia
Tel: 071 238 138
Fax: 071 231 713
Email: pcmtunisie@pcmpompes.com
Web: www.pcmpompes.com

TURKEY (TR)

ABS Pompalari Ltd
 Atasehir Bulvari
 ABS Plaza No 40, Kat: 3
 Atasehir-Istanbul 34758
 Turkey

Tel: 0216 455 2256
Fax: 0216 455 2265
Email: info@absgroup.com
Web: www.absgroup.com

Türbosan AS
 Gumussuyu Cad Hastane
 Yolu No1 Maltepe
 Istanbul 34010
 Turkey
Tel: 0212 567 9550
Fax: 0212 612 4741
Email: info@turbosan.com
Web: www.turbosan.com

Yaltek AS
 Halk Sk Eksioglu Is Merkezi 28
 Kozyatagi
 Istanbul 634734
 Turkey
Tel: 0216 661 0203
Fax: 0216 661 0212
Email: ercument@hotmail.com.tr
Web: www.yaltek.com

UKRAINE (UA)

Nasosenergomash
 1 Privokzalnaya Square
 Sumy 40011
 Ukraine
Tel: 0542 257172
Fax: 0542 258894
Email: ves@nempump.com
Web: www.nempump.com

UNITED ARAB EMIRATES (AE)

Primax Pumps
 PO Box 17505
 Office Lob 11-7, Jebel Ali Freezone
 Dubai
 United Arab Emirates
Tel: 04 8811599
Fax: 04 8818883
Email: primax@primax.ae
Web: www.sykesgroup.com

UNITED KINGDOM (UK)

ABS Wastewater Technology Ltd
 Unit 1, Elm Park Court
 Tilgate Forest Business Park
 Crawley
 West Sussex
 RH11 9BP
 United Kingdom
Tel: 01293 744800
Fax: 01293 543392
Email: info@absgroup.com
Web: www.absgroup.com

Air Pumping Engineering Service
 PO Box 239
 East Ham
 London
 E6 3SG
 United Kingdom
Tel: 020 8552 1172
Fax: 020 8470 4617
Email: sales@airpumping.co.uk
Web: www.airpumping.co.uk

Albany Engineering Company Ltd
 Church Road
 Lydney
 Gloucestershire
 GL15 5EQ
 United Kingdom
Tel: 01594 842275
Fax: 01594 842574
Email: sales@albany-pumps.co.uk
Web: www.albany-pumps.co.uk

Alfa Laval Pumps Ltd
 Birch Road
 Eastbourne
 East Sussex
 BN23 6PQ
 United Kingdom
Tel: 01323 412555
Fax: 01323 414515
Email: bob.heales@alfalaval.com
Web: www.alfalaval.com

Allidos Ltd
 39 Gravelly Industrial Park
 Tyburn Road
 Birmingham
 B24 8TL
 United Kingdom
Tel: 0121 328 3336
Fax: 0121 328 4332
Email: alldos.uk@alldos.com
Web: www.alldos.com

Allpumps Ltd
 448 Brightside Lane
 Sheffield
 S9 2SP
 United Kingdom
Tel: 0114 2442203
Fax: 0114 2425885
Email: sales@allpumps.co.uk
Web: www.allpumps.co.uk

Alpeco Ltd
 Chinnor Road
 Bledlow
 Buckinghamshire
 HP27 9PH
 United Kingdom
Tel: 01844 342666
Fax: 01844 345286
Email: sales@alpeco.co.uk
Web: www.alpeco.co.uk

Charles Austen Pumps Ltd
 Royston Road
 Byfleet
 Weybridge
 Surrey
 KY14 7NY
 United Kingdom
Tel: 01932 355277
Fax: 01932 351285
Email: info@charlesausten.com
Web: www.charlesausten.com

Autoclude Pumps
 Arisdale Avenue
 South Ockendon
 Essex
 RM15 5DP
 United Kingdom
Tel: 01708 856125
Fax: 01708 857366

Email: info@autocludepumps.com
Web: www.autocludepumps.com

AxFlow Ltd

Orion Park, Northfield Avenue
 Ealing
 London
 W13 9SJ
 United Kingdom
Tel: 020 8579 2111
Fax: 020 8579 7326
Email: info@axflow.co.uk
Web: www.axflow.co.uk

Beresford Pumps

Unit 7 Network Park, Duddeston Mill Road
 Saltley
 Birmingham
 B8 1AU
 United Kingdom
Tel: 0121 503 3001
Fax: 0121 503 3002
Email: sales@beresfordpumps.co.uk
Web: www.beresfordpumps.co.uk

BOC Edwards - Hick Hargreaves

Wingates Industrial Estate
 Great Bank Road
 Westhoughton
 Bolton
 BL5 3SL
 United Kingdom
Tel: 01942 652652
Fax: 01942 652651
Email: hick.hargreaves@bocedwards.com
Web: www.bocedwards.com

Brook Crompton

St Thomas Road
 Huddersfield
 HD1 3LJ
 United Kingdom
Tel: 01484 557200
Fax: 01484 557201
Email: csc@brookcrompton.com
Web: www.brookcrompton.com

Camaction Avonpump Ltd

The Farthings, 11 Arnor Close
 Worle
 Weston-super-Mare
 Somerset
 BS22 7GB
 United Kingdom
Tel: 01934 520091
Fax: 01934 513062
Email: enquiries@camaction.co.uk
Web: www.camaction.co.uk

Caster HMD Kontro

Hampden Park Industrial Estate
 Eastbourne
 East Sussex
 BN22 9AN
 United Kingdom
Tel: 01323 452000
Fax: 01323 503369
Email: pumps@hmdpumps.com
Web: www.sundyne.com

CAT Pumps (UK) Ltd

1 Fleet Business Park
 Sandy Lane, Church Crookham
 Fleet
 Hampshire

GU52 8BF
 United Kingdom
Tel: 01252 622031
Fax: 01252 626655
Email: sales@catpumps.co.uk
Web: www.catpumps.com

Ceetak Engineering Ltd

Bedford Business Centre
 Mile Road
 Bedford
 MK42 9TW
 United Kingdom
Tel: 01234 343232
Fax: 01234 341133
Email: bedford@ceetakengineering.com
Web: www.ceetakengineering.com

Chem Resist Group Ltd

Britannia House, Lockway
 Ravensthorpe Industrial Estate
 Dewsbury
 West Yorkshire
 WF13 3SX
 United Kingdom
Tel: 01924 499466
Fax: 01924 490334
Email: enquiry@chemresist.com
Web: www.chemresist.com

Chemvac Pumps Ltd

Redwood
 Tytherington Business Park
 Macclesfield
 Cheshire
 SK10 2XH
 United Kingdom
Tel: 01625 443170
Fax: 01625 443179
Email: chemvacpumps@ltd@aol.com
Web: www.chemvacpumps.co.uk

Circulating Pumps Ltd

Oldmedow Road
 Hardwick Industrial Estate
 King's Lynn
 Norfolk
 PE30 4PP
 United Kingdom
Tel: 01553 764821
Fax: 01553 760965
Email: info@circulatingpumps.net
Web: www.circulatingpumps.net

Concentric Pumps Ltd

Unit 10, Gravelly Industrial Estate
 Birmingham
 B24 8HW
 United Kingdom
Tel: 0121 327 2081
Fax: 0121 327 6187
Email: sales@concentric-pumps.co.uk
Web: www.concentric-pumps.co.uk

Cougar Industries Ltd

1 River Park
 Billet Lane
 Berkhamsted
 Hertfordshire
 HP4 1HL
 United Kingdom
Tel: 01442 860000
Fax: 01442 864686
Web: www.cougar-global.com

John Crane UK Ltd

Buckingham House
 Buckingham Avenue
 Slough
 SL1 4LU
 United Kingdom
Tel: 01753 224052
Fax: 01753 224155
Email: sloughexportsales@johncrane.co.uk
Web: www.johncrane.co.uk

Crane Process Flow Technologies Ltd

Grange Road
 Cwmbran
 Gwent
 NP44 3XX
 United Kingdom
Tel: 01633 486666
Fax: 01633 486777
Web: www.craneflow.com

Crest Pumps Ltd

163 Stourvale Road
 Southbourne
 Bournemouth
 BH6 5HQ
 United Kingdom
Tel: 01202 425000
Fax: 01202 425577
Email: enquiries@crestpumps.co.uk
Web: www.crestpumps.co.uk

Dawson Downie Lamont

Unit 31, Rutherford Road
 Southfield Industrial Estate
 Glenrothes
 KY6 2RT
 United Kingdom
Tel: 01592 775577
Fax: 01592 775517
Email: sales@ddl-ltd.com
Web: www.ddl-ltd.com

Diaphragm Pumps Ltd

244 Grindley Lane
 Blythe Bridge
 Stoke on Trent
 ST11 9LW
 United Kingdom
Tel: 01782 393939
Fax: 01782 394949
Email: sales@diaphragmpumps.co.uk
Web: www.pump-shop.co.uk

Flo-Dyne Ltd

Flo-Dyne Place
 Asheridge Business Centre
 Asheridge Road
 Chesham
 Buckinghamshire
 HP5 2PT
 United Kingdom
Tel: 01494 770088
Fax: 01494 770099
Email: sales@flo-dyne.net
Web: www.flo-dyne.net

Flotronic Pumps Ltd

Ricebridge Works, Brighton Road
 Bolney
 West Sussex
 RH17 5NA
 United Kingdom
Tel: 01444 881871

Fax: 01444 881860
Email: salesdept@flotronicpumps.co.uk
Web: www.flotronicpumps.co.uk

Flowguard Ltd
 Watford Bridge
 New Mills
 Stockport
 SK12 4HJ
 United Kingdom
Tel: 01663 745976
Fax: 01663 742788
Email: swheatley@flowguard.com
Web: www.flowguard.demon.co.uk

Flowsolve Ltd
 Middle Floor
 40 High Street
 London
 SW19 5AU
 United Kingdom
Tel: 020 3274 4010
Fax: 020 3274 4011
Email: cfd@flowsolve.com
Web: www.flowsolve.com

Fristam Pumps (UK) Ltd
 Unit 11, Apex Business Centre
 Diplocks Way
 Hailsham
 East Sussex
 BN27 3JF
 United Kingdom
Tel: 01323 849849
Fax: 01323 849438
Email: info@fristam.co.uk
Web: www.fristam.de

Gilbert Gilkes & Gordon Ltd
 Canal Head North
 Kendal
 Cumbria
 LA9 7BZ
 United Kingdom
Tel: 01539 720028
Fax: 01539 732110
Email: enquiries@gilkes.com
Web: www.gilkes.com

Godwin Pumps Ltd
 Quenington
 Cirencester
 Gloucestershire
 GL7 5BX
 United Kingdom
Tel: 01285 750271
Fax: 01285 750352
Email: sales@godwinpumps.co.uk
Web: www.godwinpumps.co.uk

Goodwin International
 Goodwin House, Leek Road
 Hanley
 Stoke on Trent
 ST1 3NR
 United Kingdom
Tel: 01782 208040
Fax: 01782 851050
Email: pumps@goodwingroup.com
Web: www.goodwin.co.uk

Graham Vacuum Pumps Ltd
 Forge Lane
 Congleton
 Cheshire

CW12 4HG
 United Kingdom
Tel: 01260 274721
Fax: 01260 276965
Web: www.grahamvt.com

Grundfos Pumps Ltd
 Grovebury Road
 Leighton Buzzard
 Bedfordshire
 LU7 4TL
 United Kingdom
Tel: 01525 850000
Email: sales@grundfos.com
Web: www.grundfos.com

Hale Products Europe Ltd
 Charles Street
 Warwick
 CV34 5LR
 United Kingdom
Tel: 01926 623600
Fax: 01926 623666
Email: admin_haleuk@idexcorp.com
Web: www.haleeurope.com

Hamworthy KSE
 Fleets Corner
 Poole
 Dorset
 BH17 0JT
 United Kingdom
Tel: 01202 662600
Fax: 01202 666363
Email: poolepumps@hamworthy.com
Web: www.hamworthy.com

Hayward Tyler® Group
 1 Kimpton Road
 Luton
 LU1 3LD
 United Kingdom
Tel: 01582 731144
Fax: 01582 393400
Email: haywardtyler@haywardtyler.com
Web: www.haywardtyler.com

Heypac Ltd
 Unit 3, The Royston Centre
 Lynchford Road
 Ash Vale
 Hampshire
 GU12 5PQ
 United Kingdom
Tel: 01252 511003
Fax: 01252 519003
Email: enquiries@heypac.co.uk
Web: www.heypac.co.uk

Hidrostal Ltd
 4-5 The Galloway Centre
 Hambridge Lane
 Newbury
 Berkshire
 RG14 5TL
 United Kingdom
Tel: 01635 550440
Fax: 01635 550140
Email: sales@hidrostal.co.uk
Web: www.hidrostal.co.uk

Hilge Pumps Ltd
 Hawthorn Road
 Eastbourne
 East Sussex

BN23 6QA
 United Kingdom
Tel: 01323 438333
Fax: 01323 410004
Email: pumps@hilge.co.uk
Web: www.hilge.de

HMD/Kontro Sealless Pumps
See: Caster HMD Kontro

Hydrainer Pumps Ltd
 Norwood Industrial Estate
 Rotherham Close, Killamarsh
 Sheffield
 S21 2JU
 United Kingdom
Tel: 01142 484868
Fax: 01142 510136
Email: pumpsales@hydrainer.com
Web: www.hydrainer.com

Invensys APV UK
 23 Gatwick Road
 Crawley
 West Sussex
 RH10 9JB
 United Kingdom
Tel: 01293 527777
Fax: 01293 552640
Email: apvproducts.uk@invensys.com
Web: www.apv.com

Jabsco UK, ITT Industries
 Bingley Road
 Hoddesdon
 Hertfordshire
 EN11 0BU
 United Kingdom
Tel: 01992 450145
Fax: 01992 467132
Web: www.jabsco.com

JLS International (UK) Ltd
 62 Mill Road
 Ringmer
 Lewes
 East Sussex
 BN8 5HZ
 United Kingdom
Tel: 01273 812029
Fax: 01273 812029
Email: info@jlsintl.com
Web: www.jlsintl.com

Johnson Pump (UK) Ltd
 Highfield Industrial Estate
 Edison Road
 Eastbourne
 East Sussex
 BN23 6PT
 United Kingdom
Tel: 01323 509211
Fax: 01323 507306
Email: jinfo@idexcorp.com
Web: www.johnsonpump.com

JP Pumps Ltd
 Maxwell Way
 Crawley
 West Sussex
 RH10 9SA
 United Kingdom
Tel: 01293 553495
Fax: 01293 524635

Email: mail@jppumps.co.uk
Web: www.pandct.co.uk

Kecol Pumps Ltd

Faraday Drive
 Bridgnorth
 Shropshire
 WV15 5BJ
 United Kingdom
Tel: 01746 764311
Fax: 01746 764780
Email: sales@kecol.co.uk
Web: www.kecol.co.uk

Kestner Engineering Co Ltd

Bredgar Road
 Gillingham
 Kent
 ME8 6PN
 United Kingdom
Tel: 01634 386689
Fax: 01634 386684
Email: sales@kestner-eng.co.uk
Web: www.kestner-eng.co.uk

Kinder-Janes Engineers Ltd

Porters Wood
 St Albans
 Hertfordshire
 AL3 6HU
 United Kingdom
Tel: 01727 844441
Fax: 01727 844247
Email: info@kinder-janes.co.uk
Web: www.kinder-janes.co.uk

KSB Ltd

2 Cotton Way
 Loughborough
 Leicestershire
 LE11 5TF
 United Kingdom
Tel: 01509 231872
Fax: 01509 215228
Email: ian.robinson@ksb.com
Web: www.ksb.com

KTR Couplings Ltd

Unit 7, Acorn Business Park
 Woodseats Close
 Sheffield
 S8 0TB
 United Kingdom
Tel: 0114 258 7757
Fax: 0114 258 7740
Email: ktr-uk@ktr.com
Web: www.ktr.com

Linatex Ltd

Wilkinson House, Galway Road
 Blackbushe Business Park
 Yateley
 Hampshire
 GU46 6GE
 United Kingdom
Tel: 01252 743000
Fax: 01252 743030
Web: www.linatex.com

London Pumps Ltd

Unit 7, Hampden Road
 Kingston-Upon-Thames
 KT1 3LG
 United Kingdom
Tel: 020 8546 7702

Fax: 020 8546 7703

Email: sales@londonpumps.co.uk

Web: www.londonpumps.co.uk

Lutz (UK) Ltd

West Midlands Freeport
 Birmingham
 B26 3QD
 United Kingdom
Tel: 0121 782 2662
Fax: 0121 782 2680
Email: sales@lutzpump.co.uk
Web: www.lutzpump.co.uk

March May Ltd

Eaton Works, Howard Road
 Eaton Socon
 St Neots
 Cambridgeshire
 PE19 3NZ
 United Kingdom
Tel: 01480 214444
Fax: 01480 405336
Email: sales@marchmay.co.uk
Web: www.marchmay.co.uk

MDM Pumps Ltd

Spring Lane
 Malvern
 Worcestershire
 WR14 1BP
 United Kingdom
Tel: 01684 892678
Fax: 01684 892841
Email: info@mdmpumps.co.uk
Web: www.hygienic-pumps.co.uk

Megator Ltd

Hendon
 Sunderland
 Tyne & Wear
 SR1 2NQ
 United Kingdom
Tel: 0191 567 4888
Fax: 0191 567 8512
Email: info@megator.co.uk
Web: www.megator.co.uk

Micropump Ltd

Howard Road
 Eaton Socon
 St Neots
 Cambridgeshire
 PE 19 8ET
 United Kingdom
Tel: 01480 356900
Fax: 01480 356920
Email: info.micropump@idexcorp.com
Web: www.micropump.com

Midland Pump Manufacturing Co Ltd

Seeleys Road
 Greet
 Birmingham
 B11 2LF
 United Kingdom
Tel: 0121 773 8862
Fax: 0121 771 4363
Email: enquiries@midlandpump.co.uk
Web: www.midlandpump.co.uk

Mono Pumps Ltd

Martin Street
 Audenshaw
 Manchester

M34 5JA

United Kingdom

Tel: 0161 339 9000

Fax: 0161 344 0727

Email: info@mono-pumps.com

Web: www.mono-pumps.com

NSK Europe - European Bearings Business Unit

Newark
 Nottinghamshire
 NG24 2JF
 United Kingdom
Tel: 01636 605 123
Fax: 01636 602 750
Email: info-uk@nsk.com
Web: www.eu.nsk.com

Papa Pump Ltd

14a Kingshill Industrial Estate
 Bude
 Cornwall
 EX23 8QN
 United Kingdom
Tel: 01288 354454
Fax: 01288 354454
E-mail: salesinfopapa@aol.com
Web: www.waterpoweredpumps.co.uk

PCA Engineers Ltd

Homer House
 Sibthorp Street
 Lincoln
 LN5 7SB
 United Kingdom
Tel: 01522 530106
Fax: 01522 511703
Email: info@pcaeng.co.uk
Web: www.pcaeng.co.uk

PCM Pumps Ltd

Pilot Road
 Phoenix Parkway
 Corby
 Northamptonshire
 NN17 5YF
 United Kingdom
Tel: 01536 740200
Fax: 01536 740201
Email: sales@pcmpumps.co.uk
Web: www.pcmpumps.co.uk

Plenty Mirrlees Pumps

SPX Process Equipment
 Earl Haig Road, Hillington
 Glasgow
 G52 4JN
 United Kingdom
Tel: 0141 883 0314
Fax: 0141 882 2752
Email: pumps.plenty@processequipment.spx.com
Web: www.spxprocessequipment.com

ProMinent Fluid Controls UK Ltd

Resolution Road
 Ashby-de-la-Zouch
 Leicestershire
 LE65 1DW
 United Kingdom
Tel: 01530 560555
Fax: 01530 560777
Email: info@prominent.co.uk
Web: www.prominent.co.uk

Pulseguard Ltd

Unit 1, Greg Street Industrial Centre
Greg Street, Reddish
Stockport
SK5 7BS
United Kingdom
Tel: 0161 442 6222
Fax: 0161 443 1486
Email: pulse@plsgd.co.uk
Web: www.pulsegurad.co.uk

Pump & Package Ltd

29E Station Road
Desborough
Northamptonshire
NN14 2RL
United Kingdom
Tel: 01536 762674
Fax: 01536 761973
Email: pumppackage@btconnect.com
Web: www.pumppackage.co.uk

Pump Centre, ESR Technology Ltd

Whittle House, 410 The Quadrant
Birchwood Park
Warrington
WA3 6FW
United Kingdom
Tel: 01925 843506
Fax: 01925 843500
Email: pumps@esrtechnology.com
Web: www.pumpcentre.com

Pump Engineering Ltd

Riverside Estate
Littlehampton
West Sussex
BN17 5DF
United Kingdom
Tel: 01903 730900
Fax: 01903 730234
Email: sales@pumpeng.co.uk
Web: www.pumpeng.co.uk

Putzmeister Ltd

Carrwood Road, Chesterfield Trading
Estate
Sheepbridge
Chesterfield
Derbyshire
S41 9QB
United Kingdom
Tel: 01246 264200
Fax: 01246 260077
Email: info@putzmeister.co.uk
Web: www.putzmeister.co.uk

RMI Pressure Systems Ltd

Portex House
Blaydon
Tyne & Wear
NE21 4TE
United Kingdom
Tel: 0191 499 0882
Fax: 0191 499 0883
Email: rhowarth@armlink.com
Web: www.armstrongpumps.com

Roxspur Measurement & Control Ltd

2 Downgate Drive
Sheffield
S4 8BT
United Kingdom
Tel: 0114 244 2521
Fax: 0114 243 4838

Email: sales@roxspur.com

Web: www.roxspur.com

S & G Thermofluids Ltd

The Old Tannery
Kelston
Bath
BA1 9AN
United Kingdom
Tel: 0117 932 7378
Fax: 0117 932 9652
Email: tony.smith@thermofluids.co.uk
Web: www.thermofluids.co.uk

Schaeffler (UK) Ltd

Forge Lane
Minworth
Sutton Coldfield
West Midlands
B76 1AP
United Kingdom
Tel: 0121 351 3833
Fax: 0121 351 7686
Email: info.uk@schaeffler.com
Web: www.ina.co.uk

seepex UK Ltd

3 Armtech Row
Houndstone Business Park
Yeovil
Somerset
BA22 8RW
United Kingdom
Tel: 01935 472376
Fax: 01935 479836
Email: sales@seepex.co.uk
Web: www.seepex.com

Seko Ltd

Units 8a & 8b, Blackminster Business Park
Old Birmingham Road
Blackminster
Worcestershire
WR11 7RE
United Kingdom
Tel: 01386 839010
Email: s.ellix@seko.com
Web: www.selko.com

Selwood Group Ltd

Bournemouth Road
Chandlers Ford
Eastleigh
Hampshire
SO53 3ZL
United Kingdom
Tel: 023 8026 6311
Fax: 023 8026 0906
Email: cfordhire@selwoodgroup.co.uk
Web: www.selwood-pumps.co.uk

Serfilco Europe Ltd

Broad Oak Industrial Park
Ashburton Road West
West Trafford
Manchester
M17 1RW
United Kingdom
Tel: 0161 872 1317
Fax: 0161 873 8027
Email: sales@serfilco-europe.com
Web: www.serfilco.com

SHURflo Ltd

Unit 5, Sterling Park

Gatwick Road
Crawley
West Sussex
RH10 2QT
United Kingdom
Tel: 01293 424050
Fax: 01293 421880
Email: sales@shurflo.co.uk
Web: www.shurflo-original.com

Michael Smith Engineers Ltd

Unit 9, Batley Enterprise Centre
513 Bradford Road
Batley
Yorkshire
WF17 8JY
United Kingdom
Tel: 01483 771871
Fax: 01483 723110
Email: info@michael-smith-engineers.co.uk
Web: www.michael-smith-engineers.co.uk

SPP Pumps Ltd

Theale Cross
Pincent Lane, Calcot
Reading
Berkshire
RG31 7SP
United Kingdom
Tel: 0118 932 3123
Fax: 0118 932 3302
Email: solutions@spppumps.com
Web: www.spppumps.com

SPX Process Equipment Ltd

Ironstone Way
Brixworth
Northampton
NN6 9UD
United Kingdom
Tel: 01604 880751
Fax: 01604 880145
Email: info.uk@processequipment.spx.com
Web: www.spxpe.com

Sterling Fluid Systems (UK) Ltd

Atlantic Street
Altrincham
Cheshire
WA14 5DH
United Kingdom
Tel: 0161 928 6371
Fax: 0161 925 2129
Email: uksales@sterlingfluid.com
Web: www.sterlingfluid.com

SKF (UK) Ltd

Luton
LU3 3BL
United Kingdom
Tel: 01582 490049
Fax: 01582 848091
Email: marketing.uk@skf.com
Web: www.skf.co.uk

Terex Powertrain Ltd

Catto Drive
Peterhead
Aberdeen
AR42 1RL
United Kingdom
Tel: 01779 473161
Fax: 01779 477424

Totton Pumps Ltd

Rushington Business Park
Totton
Southampton
SO40 9AH
United Kingdom
Tel: 023 8066 6685
Fax: 023 8066 6880
Email: info@totton-pumps.com
Web: www.totton-pumps.co.uk

TriVista Engineering Ltd

The Sussex Innovation Centre
Science Park Square
Falmer, Brighton
BN1 9SB
United Kingdom
Tel: 01273 704419
Fax: 0870 4604950
Email: mail@trivista.co.uk
Web: www.trivista.co.uk

Stuart Turner Ltd

The Market Place
Henley-on-Thames
Oxfordshire
RG9 2AD
United Kingdom
Tel: 01491 572655
Fax: 01491 573704
Email: pumps@stuart-turner.co.uk
Web: www.stuart-turner.co.uk

Wallace & Tiernan, Chemfeed Ltd

Priory Works
Five Oak Green Road
Tonbridge
Kent
TN11 0QL
United Kingdom
Tel: 01732 771777
Fax: 01732 771800
Email: inform@wallace-tiernan.com
Web: www.wallace-tiernan.com

Wanner International Ltd

Units 8-9 Fleet Business Park
Sandy Lane
Church Crookham
Hampshire
GU52 8BF
United Kingdom
Tel: 01252 816847
Fax: 01252 781235
Email: sales@wannerint.com
Web: www.hydra-cell.com

Watson-Marlow Bredel Pumps Ltd

Falmouth
Cornwall
TR11 4RU
United Kingdom
Tel: 01326 370370
Fax: 01326 376009
Email: info@watson-marlow.co.uk
Web: www.watson-marlow.co.uk

Weir Pumps Ltd

149 Newlands Road
Cathcart
Glasgow
G44 4EX
United Kingdom
Tel: 0141 637 7141

Fax: 0141 633 7358
Email: enquiries@weirpumps.com
Web: www.weirclearliquid.com

UNITED STATES**(US)****ABS Pumps Inc**

140 Pond View Drive
Meridien
CT 06450
USA
Tel: 203 238 2700
Fax: 203 238 0738
Email: info@absgroup.com
Web: www.absgroup.com

ACD Inc

2321 South Pullman Street
Santa Ana
CA 92705
USA
Tel: 949 261 7533
Fax: 949 261 6285
Email: jpaje@acdcom.com
Web: www.acdcom.com

Ace Pump Corporation

PO Box 13187, 1650 Channel Avenue
Memphis
TN 38113
USA
Tel: 901 948 8514
Fax: 901 774 6147
Email: sales@acepumps.com
Web: www.acepumps.com

Alfa Laval Inc

5400 International Trade Drive
Richmond
VA 23231
USA
Tel: 804 222 5300
Fax: 804 545 8311
Web: www.alfalaval.com

American Lewa Inc

132 Hopping Brook Road
Holliston
MA 01746
USA
Tel: 508 429 7403
Fax: 508 429 8615
Email: sales@amlewa.com
Web: www.amlewa.com

Ansimag Inc

14845 West 64th Avenue
Arvada
CO 80007
USA
Tel: 847 290 0482
Fax: 847 290 0481
Email: sales@ansimag.com
Web: www.ansimag.com

Aurora Pump

800 Airport Road
North Aurora
IL 60542
USA
Tel: 630 859 7000
Fax: 630 859 1226
Email: aurora_info@pentairpump.com
Web: www.aurorapump.com

Barnant Company

28 W 092 Commercial Avenue
Barrington
IL 60010
USA
Tel: 847 381 7050
Fax: 847 381 7053
Email: barnant@barnant.com
Web: www.barnant.com

Beta Technology Inc

2841 Mission Street
Santa Cruz
CA 95060
USA
Tel: 831 426 0882
Fax: 831 423 4573
Email: service@beta-technology.com
Web: www.beta-technology.com

Bijur Lubricating Corporation

808 Aviation Parkway
Suite 1400
Morrisville
NC 27560
USA
Tel: 919 465 4448
Fax: 919 465 0516
Email: cservice@bijurlube.com
Web: www.bijur.com

Blue White Industries

5300 Business Drive
Huntington Beach
CA 92649
USA
Tel: 714 893 8529
Fax: 714 894 9492
Email: sales@blue-white.com
Web: www.blwhite.com

Buffalo Pumps Inc

874 Oliver Street
North Tonawanda
Niagara
NY 14120-3298
USA
Tel: 716 693 1850
Fax: 716 693 6303
Email: info@buffalopumps.com
Web: www.buffalopumps.com

Carver Pump Company

2415 Park Avenue
Muscatine
IA 52761-5691
USA
Tel: 563 263 3410
Fax: 563 267 0510
Email: customerservice@carverpump.com
Web: www.carverpump.com

CAT Pumps

1681 94th Lane NE
Minneapolis
MN 55449
USA
Tel: 763 780 5440
Fax: 763 780 2958
Email: techsupport@catpumps.com
Web: www.catpumps.com

CDS-John Blue Company

PO Box 1607

Huntsville
AL 35807
USA
Tel: 205 721 9090
Fax: 205 721 9091
Email: info@cds-johnblue.com
Web: www.cds-johnblue.com

Chempump
959 Mearns Road
Warminster
PA 18974
USA
Tel: 215 343 6000
Fax: 215 343 8543
Email: chempump@chempump.com
Web: www.chempump.com

Chicago Pump Company
PO Box 6620
Aurora
IL 60598-0620
USA
Tel: 630 236 5700
Fax: 630 236 5779
Email: sales@yccpump.net
Web: www.yccpump.com

Cole-Parmer Instrument Company
625 East Bunker Court
Vernon Hills
IL 60061-1844
USA
Tel: 800 323 4340
Fax: 847 247 2929
Email: export@coleparmer.com
Web: www.coleparmer.com

Colfax Pump Group
1710 Airport Road
PO Box 5020
Monroe
NC 28111-5020
USA
Tel: 704 289 6511
Fax: 704 289 4839
Email: welcome@colfaxpump.com
Web: www.colfaxpump.com

Continental Pump Company
PO Box 428
Warrenton
MO 63383-0428
USA
Tel: 636 456 6006
Fax: 636 456 4337
Email: info@continentalultrapumps.com
Web: www.continentalultrapumps.com

Corken Inc
3805 NW 36th Street
Oklahoma City
OK 73112
USA
Tel: 405 946 5576
Fax: 405 948 7343
Email: info.corken@idexcorp.com
Web: www.corken.com

Cornell
Sunrise Corridor Business Center
16261 SE 130th Avenue
Clackamas
OR 97015
USA

Tel: 503 653 0330
Fax: 503 653 0338
Email: info@cornellpump.com
Web: www.cornellpump.com

Crane Pumps & Systems
420 Third Street
Piqua
OH 45356
USA
Tel: 937 773 2442
Fax: 937 773 2238
Email: cranepumps@cranepumps.com
Web: www.cranepumps.com

Cross Manufacturing Inc
100 James H Cross Boulevard
Lewis
KS 67552
USA
Tel: 620 324 5525
Fax: 620 324 5737
Email: info@crossmfg.com
Web: www.crossmfg.com

CW-EMD
1000 Cheswick Avenue
Cheswick
PA 15024
USA
Tel: 724 275 5000
Fax: 724 275 5942
Email: contact@emd.curtisswright.com
Web: www.wxemd.com

Darley Pumps
2000 Anson Drive
Melrose Park
IL 60160
USA
Tel: 708 345 8050
Fax: 708 345 8993
Email: darley@darley.com
Web: www.darley.com

**Dean Pump Division,
Met-Pro Corporation**
6040 Guion Road
Indianapolis
IN 46254
USA
Tel: 317 293 2930
Fax: 317 297 7028
Email: info@met-pro.com
Web: www.deanpump.com

Defco
PO Box 1209
Decatur
AL 35602
USA
Tel: 256 353 7697
Fax: 256 350 6540
Email: sales@(no-spam)defcoinc.com
Web: www.defco.com

Dempster Industries Inc
PO Box 848
711 South 6th Street
Beatrice
NE 68310
USA
Tel: 402 223 4026
Fax: 402 228 4389

Email: sales@dempsterinc.com
Web: www.dempsterinc.com

Discflo Corporation
10850 Hartley Road
Santee
CA 92071
USA
Tel: 619 596 3181
Fax: 619 449 1990
Email: sales@discflo.com
Web: www.discflo.com

Ebara Fluid Handling
1651 Cedar Line Drive
Rock Hill
SC 29730
USA
Tel: 803 327 5005
Fax: 803 327 5097
Email: info@pumpsebara.com
Web: www.pumpsebara.com

EMS Pacific
4480 Enterprise Street
Suite D
Fremont
CA 94538
USA
Tel: 510 668 0405
Fax: 510 668 1012
Email: info@emspacific.com
Web: www.emspacific.com

Environamics Corporation
19 Executive Drive
Hudson
NH 03051
USA
Tel: 603 889 0200
Fax: 603 889 2508
Email: sales@environamics.com
Web: www.environamics.com

ESSCO Pumps & Controls
4935 Telegraph Road
Los Angeles
CA 90022
USA
Tel: 213 261 2181
Fax: 213 261 1532
Email: sales@esscopumps.com
Web: www.esscopumps.com

Fairbanks Morse Pump
3601 Fairbanks Avenue
Kansas City
KS 66106
USA
Tel: 913 371 5000
Fax: 913 748 4025
Email: fairbanks_info@pentairpump.com
Web: www.fairbanksmorsepump.com

Finish Thompson Inc
921 Greengarden Road
Erie
PA 16501
USA
Tel: 814 455 4478
Fax: 814 455 8518
Web: www.finishthompson.com

Flojet Corporation
1800 Gardner Expressway

Quincy
IL 62301
USA
Tel: 217 222 5400
Fax: 217 224 7814
Email: pumps@gardnerdenver.com
Web: www.gardnerdenver.com

Flowserve Corporation
5215 North O'Connor Boulevard
Suite 2300
Irving
TX 75039
USA
Tel: 972 443 6500
Fax: 972 443 6800
Email: fpdinformation@flowserve.com
Web: www.flowserve.com

Fluid Metering Inc
5 Aerial Way, Suite 500
Syosset
Ny 11791
USA
Tel: 516 922 6050
Fax: 516 624 8261
Email: pumps@fmipump.com
Web: www.fmipump.com

Flux Pumps Corporation
4330 Commerce Circle
Atlanta
GA 30336
USA
Tel: 404 691 6010
Fax: 404 691 6314
Web: www.flux-pumps.com

Fristam Pumps USA
2410 Parview Road
Middleton
WI 53562-2524
USA
Tel: 608 831 5001
Fax: 608 831 8467
Email: info@fristampumps.com
Web: www.fristampumps.com

Fultz Pumps Inc
PO Box 550
5690 State Route 103 North
Lewistown
PA 17044
USA
Tel: 717 248 2300
Fax: 717 248 5458
Email: fultzpumps@acsworld.com
Web: www.fultzpumps.com

GIW Industries Inc
5000 Wrightsboro Road
Grovetown
GA 30813-9750
USA
Tel: 706 863 1011
Fax: 706 863 5637
Email: marketing@giwindustries.com
Web: www.giwindustries.com

Godwin Pumps of America Inc
One Floodgate Road
Bridgeport
NJ 08014
USA
Tel: 856 467 3636

Fax: 856 467 4841
Email: sales@godwinpumps.com
Web: www.godwinpumps.com

Gorman-Rupp Company
305 Bowman Street
Mansfield
OH 4903-1600
USA
Tel: 419 755 1011
Fax: 419 755 1266
Email: intsales@gormanrupp.com
Web: www.gormanrupp.com

Goulds Pumps, ITT Industrial & BioPharm Group
240 Fall Street
Seneca Falls
NY 13148
USA
Tel: 315 568 2811
Fax: 315 568 7759
Email: gpsales@itt.com
Web: www.gouldspumps.com

Goulds Pumps, ITT Water Technology
PO Box 330
Seneca Falls
NY 13148
USA
Tel: 315 568 2811
Fax: 315 568 7759
Web: www.goulds.com

GPM Pumps Inc
110 Gateway Drive
Macon
GA 31210
USA
Tel: 877 476 3569
Email: info@gmpump.com
Web: www.gmppump.com

Graco Inc
88 11th Avenue NE
Minneapolis
MN 55413
USA
Tel: 612 623 6704
Fax: 612 623 6957
Web: www.graco.com

Grover Manufacturing Corporation
620 Vail Avenue
PO Box 986
Montebello
CA 90640
USA
Tel: 323 724 3444
Fax: 323 724 3596
Email: sales@grovermfg.com
Web: www.grovermfg.com

Grundfos Pumps Corporation
17100 West 118th Terrace
Olathe
KS 66061
USA
Tel: 913 227 3400
Email: partnerservices@US.grundfos.com
Web: www.grundfos.com

Haight Pumps
Division of Baker Manufacturing Company
133 Enterprise Street

Evansville
WI 53536
USA
Tel: 608 871 9250
Fax: 608 882 3777
Email: haight@baker-mfg.com
Web: www.haightpump.com

Haskel International Inc
100 East Graham Place
Burbank
CA 91502
USA
Tel: 818 843 4000
Fax: 818 841 4291
Email: sales@haskel.com
Web: www.haskel.com

Hydromatic Pumps
740 East 9th Street
Ashland
OH 44805
USA
Tel: 419 207 3372
Fax: 419 281 4087
Web: www.hydromatic.com

Hypro
375 Fifth Avenue NW
New Brighton
MN 55112
USA
Tel: 651 766 6300
Fax: 651 766 6600
Email: sales@hypropumps.com
Web: www.hypropumps.com

Ingersoll-Rand/ARO
Business Development Center
1467 Route 31 South, PO Box 970
Annandale
NJ 08801
USA
Tel: 800 495 0276
Web: www.irtools.com

Invensys APV
100 South CP Avenue
Lake Mills
WI 53551
USA
Tel: 920 648 8311
Fax: 920 648 1423
Email: apvproducts.us@invensys.com
Web: www.apv.com

ITT Residential & Commercial Water
8200 N Austin Avenue
Morton Grove
IL 60053-3283
USA
Tel: 847 966 3700
Fax: 847 966 8366
Email: fhs.webmaster@itt.com
Web: www.bellgosssett.com

Iwaki America
5 Boynton Road
Hopping Brook Park
Holliston
MA 01746
USA
Tel: 508 429 1440
Fax: 508 429 1386

Email: service@iwakiamerica.com
Web: www.iwakiamerica.com

Jabsco US, ITT Industries

20 Icon
 Foothill Ranch
 CA 92610
 USA
Tel: 949 859 4945
Fax: 949 859 1153
Web: www.jabsco.com

Jaeco Fluid Sysytems Inc

17 Lee Boulevard, Suite D
 Malvern
 PA 19355-1234
 USA
Tel: 610 407 7207
Fax: 610 407 7211
Email: sales@jaecofs.com
Web: www.jaecofs.com

Jensen

PO Box 1509, 14th & Pacific Street
 Coffeyville
 KS 67337
 USA
Tel: 620 251 5700
Fax: 620 251 3622
Email: pumpjacksales@jensen-products.com
Web: www.jensen-products.com

Johnson Pumps of America Inc

9950 W Lawrence Avenue
 Ste #300
 Schiller Park
 IL 60176
 USA
Tel: 847 671 7867
Fax: 847 671 7909
Email: jp@johnson-pump.com
Web: www.johnson-pump.com

Johnston Pump

800 Koomey Road
 Brookshire
 TX 77423
 USA
Tel: 800 926 6688
Fax: 281 934 6194
Email: puush-engrsalesmgr@sulzer.com
Web: www.johnston-pump.com

KD Scientific Inc.

84 October Hill Road
 Holliston, MA 01746
 USA
Tel: 508 429 6809
Fax: 508 893 0160
Web: www.kdscientific.com

Komline-Sanderson

12 Holland Avenue
 Peapack
 NJ 07977-0257
 USA
Tel: 908 234 1000
Fax: 908 234 9487
Email: info@komline.com
Web: www.komline.com

KTR Corporation

PO Box 90 65
 Michigan City

IN 46361

USA

Tel: 219 872 9100

Fax: 219 872 9150

Email: ktr-us@ktr.com

Web: www.ktr.com

Layne/Verti-Line

PO Box 6999
 Kansas City
 KS 66106
 USA
Tel: 913 748 4253
Fax: 913 748 4030
Email: layne_info@pentairpump.com
Web: www.pentairpump.com

Lewis Pumps

8625 Grant Road
 St Louis
 MO 63123
 USA
Tel: 314 843 4437
Fax: 314 843 7964
Email: sales@lewisumps.com
Web: www.lewisumps.com

Liquid Controls

A Unit of IDEX Corporation
 105 Albrecht Drive
 Lake Bluff
 IL 60044
 USA
Tel: 847 295 1050
Fax: 847 295 1057
Email: lc-info.lcmeter@idexcorp.com
Web: www.lcmeter.com

Little Giant Pump Company

PO Box 12010
 Oklahoma City
 OK 73157-2010
 USA
Tel: 405 947 2511
Fax: 405 947 8720
Email: customerservice@lgpc.com
Web: www.lgpc.com

LMI Milton Roy

201 Ivyland Road
 Ivyland
 PA 18974
 USA
Tel: 215 293 0401
Fax: 215 293 0445
Email: Imicustomerservice@miltonroy.com
Web: www.lmipumps.com

Lobee Pump & Machinery Company

8425 State Street
 Gasport
 NY 14067
 USA
Tel: 716 772 2651
Fax: 716 772 2555
Email: info@lobee.com
Web: www.lobee.com

Lutz-Jesco America Corporation

55 Bernar Park
 Rochester
 NY 14624
 USA
Tel: 585 426 0990

Fax: 585 426 4025

Email: mail@jescoamerica.com

Web: www.jescoamerica.com

Maag Pump Systems Textron Inc

2915 Whitehall Park Drive
 Charlotte
 NC 28273
 USA
Tel: 704 716 9000
Fax: 704 716 9001
Email: maaginfo@maagusa.textron.com
Web: www.maag.com

Madden Manufacturing Inc

PO Box 387
 Elkhart
 IN 46515
 USA
Tel: 574 295 4292
Fax: 574 295 7562
Email: info@maddenmfg.com
Web: www.maddenmfg.com

Magnatex Pumps Inc

3575 West 12th Street
 Houston
 TX 77008
 USA
Tel: 713 972 8686
Fax: 713 972 8665
Email: sales@magnatexpumps.com
Web: www.magnatexpumps.com

Mahr Metering Systems Corporation

1415-A Cross Beam Drive
 Charlotte
 NC 28217
 USA
Tel: 704 525 7128
Fax: 704 525 8290
Email: kelly.cauthen@mmscusa.com
Web: www.mmscusa.com

Marlow Pumps, ITT Water Technology

2881 East Bayard Street
 Seneca Falls
 NY 13148
 USA
Tel: 315 568 2811
Fax: 315 568 7759

Marshall Engineered Products Company

3056 Walker Ridge Drive, Suite C
 Grand Rapids
 MI 49544
 USA
Tel: 616 246 1431
Fax: 616 246 1445
Email: mepco@mepcollc.com
Web: www.mepcollc.com

Mefiag Division, Met-Pro Corporation

1550 Industrial Drive
 Owasso
 MI 48867
 USA
Tel: 989 725 8184
Fax: 989 729 1013
Email: mefiag@met-pro.com
Web: www.met-pro.com/mefiag-html

Mepco

3056 Walker Ridge Drive, Suite C
 Grand Rapids

MI 49544
USA
Tel: 616 246 1431
Fax: 616 246 1445
Email: mepco@mepcollc.com
Web: www.mepcollc.com

Micropump Inc
1402 NE 136th Avenue
Vancouver
WA 98684-0818
USA
Tel: 360 253 2008
Fax: 800 222 9565
Email: info.micropump@idexcorp.com
Web: www.micropump.com

Mody Pumps™ Inc
2166 Zeus Court
Bakersfield
CA 93308
USA
Tel: 661 392 7600
Fax: 661 392 7601
Email: sales@modypump.com
Web: www.modypump.com

Monoflo Inc
12000 West Little York
Houston
TX 77041
USA
Tel: 713 466 7999
Email: inquire@monoflo.com
Web: www.mono-pumps.com

Morgan AM & T
441 Hall Avenue
St Marys
PA 15857
USA
Tel: 814 781 1573
Fax: 814 781 9239
Web: www.morganamt.com

Morris Pumps
PO Box 6620
Aurora
IL 60598-0620
USA
Tel: 630 236 6900
Fax: 630 236 6932
Email: sales@yccpump.net
Web: www.morrispumps.com

Moyno Inc
1895 W Jefferson Street
Springfield
OH 45506
USA
Tel: 937 327 3553
Fax: 937 327 3572
Email: mipsales@moyno.com
Web: www.moyno.com

MP Pumps Inc
34800 Bennett Drive
Fraser
MI 48026-1686
USA
Tel: 586 293 8240
Fax: 586 293 8469
Email: mppumps@mppumps.com
Web: www.mppumps.com

MTH Pumps
401 West Main Street
Plano
IL 60545-1436
USA
Tel: 630 552 4115
Fax: 630 552 3688
Email: sales@mthpumps.com
Web: www.mthpumps.com

FE Myers
1101 Myers Parkway
Ashland
OH 44805
USA
Tel: 419 289 1144
Fax: 419 289 6658
Email: info@myers.com
Web: www.femyers.com

National Oilwell Varco
10000 Richmond Avenue
Houston
TX 77042-4200
USA
Tel: 713 346 7500
Web: www.natoil.com

National Pump Company LLC
7600 West Olive Avenue
Peoria
AZ 85345-7102
USA
Tel: 602 979 3560
Fax: 602 979 2177
Email: info@natlpump.com
Web: www.nationalpumpcompany.com

Neptune Chemical Pump Company Inc
PO Box 247
Lansdale
PA 19446-0247
USA
Tel: 215 699 8700
Fax: 215 699 0370
Email: pump@neptune1.com
Web: www.neptune1.com

Northern Pump
340 Benson Avenue
Grantsburg
WI 54840
USA
Tel: 715 463 8300
Fax: 715 463 5174
Email: info@northern-pump.com
Web: www.northern-pump.com

Ohler Pumps
PO Box 507, 501 Maple Street
Janesville
IA 50647
USA
Tel: 319 987 2121
Fax: 319 987 2161
Email: ohler@ohler-machinery.com
Web: www.ohler-machinery.com

The Oilgear Company
PO Box 343924
Milwaukee
WI 53234-3924
USA
Tel: 414 327 1700

Fax: 414 327 0532
Web: www.oilgear.com

Pacer Pumps
Division of ASM Industries Inc
41 Industrial Circle
Lancaster
PA 17601
USA
Tel: 717 656 2161
Fax: 717 656 0477
Email: sales@pacerpumps.com
Web: www.pacerpumps.com

Paco Pumps
800 Koomey Road
Brookshire
TX 77423
USA
Tel: 281 934 6014
Fax: 281 934 6056
Email: paco@paco-pumps.com
Web: www.paco-pumps.com

Patterson Pump Company
PO Box 790
Toccoa
GA 30577
USA
Tel: 706 886 2101
Fax: 706 886 0023
Email: bhenry@pattersonpumps.com
Web: www.pattersonpumps.com

PCM Delasco Inc
11940 Brittmoore Park Drive
Houston
TX 77041
USA
Tel: 713 896 4888
Fax: 713 896 4806
Email: pcmdelasco@pcmdelasco.com
Web: www.pcmdelasco.com

Peerless Pump Company
PO Box 7026
Indianapolis
IN 46207-7026
USA
Tel: 317 925 9661
Fax: 317 924 7388
Web: www.peerlesspump.com

Pentair Inc
5500 Wayzata Boulevard
Suite 800
Golden Valley
MN 55416-1261
USA
Tel: 763 545 1730
Fax: 763 656 5400
Web: www.pentair.com

Plast-O-Matic Valves Inc
1384 Pompton Avenue
Cedar Grove
NJ 07009
USA
Tel: 973 256 3000
Fax: 973 256 4745
Email: info@plastomatic.com
Web: www.plastomatic.com

Price Pump Company
21775 Eighth Street East

Sonoma
CA 95476
USA
Tel: 707 938 8441
Fax: 707 938 0764
Email: sales@pricepump.com
Web: www.pricepump.com

Procon Products
910 Ridgely Road
Murfreesboro
TN 37129
USA
Tel: 615 890 5710
Fax: 615 896 7729
Web: www.proconpumps.com

Pulsafeeder
Engineered Products Operation (EPO)
2883 Brighton-Henrietta Townline Road
Rochester
NY 14623
USA
Tel: 585 292 8000
Fax: 585 424 5619
Email: pulsa@idexcorp.com
Web: www.pulsa.com

Pumper Parts LLC
6017 Enterprise Drive
Export
PA 15632
USA
Tel: 724 387 1776
Fax: 724 387 1774
Email: info@pumperparts.com
Web: www.pumperparts.com

Red Jacket, ITT Water Technology
58 Wright Avenue
Auburn
NY 13021
USA
Tel: 866 325 4210
Fax: 866 325 4211
Web: www.redjacketwaterproducts.com

Reddy-Buffaloes Pump Inc
1 Dixie Drive
PO Box 557
Baxley
GA 31513
USA
Tel: 912 367 6345
Fax: 912 367 5024
Email: sales@rbpump.com
Web: www.rbpump.com

Roper Pump Company
PO Box 269
Commerce
GA 30529
USA
Tel: 706 335 5551
Fax: 706 335 5490
Email: sales@roperpumps.com
Web: www.roperpumps.com

Roth Pump Company
PO Box 4330
Rock Island
IL 61204
USA
Tel: 309 787 1791
Fax: 309 787 5142

Email: rothpump@rothpump.com
Web: www.rothpump.com

Ruhrpumpen Inc
4501 South 86th East Avenue
Tulsa
OK 74145
USA
Tel: 918 627 8400
Fax: 918 624 2471
Email: info@ruhrpumpen.com
Web: www.ruhrpumpen.com

Saint-Gobain Ceramics
23 Acheson Drive
Niagara Falls
NY 14303
USA
Tel: 716 278 6233
Fax: 716 278 2373
Email: scd.sales@saint-gobain.com
Web: www.hexoloy.com

Saint-Gobain Performance Plastics
7301 Orangewood Avenue
Garden Grove
CA 92841
USA
Tel: 800 833 5661
Fax: 714 688 2614
Web: www.microelectronics.saint-gobain.com

Serfilco Ltd
2900 MacArthur Boulevard
Northbrook
IL 60062-2005
USA
Tel: 847 509 2900
Fax: 847 559 1995
Email: sales@serfilco.com
Web: www.serfilco.com

Sethco Division, Met-Pro Corporation
800 Emlen Way
Telford
PA 18969
USA
Tel: 215 799 2577
Fax: 215 799 0920
Email: info@sethco.com
Web: www.sethco.com

SHURflo Pump Manufacturing Co
5900 Katella Avenue
Cypress
CA 90630
USA
Tel: 562 795 5200
Fax: 562 795 7564
Email: customer_service@shurflo.com
Web: www.shurflo.com

Smith & Loveless Inc
14040 Santa Fe Trail Drive
Lenexa
KS 66215-1284
USA
Tel: 913 888 5201
Fax: 913 888 2173
Email: answers@smithandloveless.com
Web: www.smithandloveless.com

SPM Flow Control Inc
7601 Wyatt Drive

Fort Worth
TX 76108
USA
Tel: 817 246 2461
Email: mtreida@spmflo.com
Web: www.spmflo.com

SRS Crisafulli Inc
1610 Crisafulli Drive
PO Box 1051
Glendive
MT 59330
USA
Tel: 406 365 3393
Fax: 406 365 8088
Email: srsc@crisafulli.com
Web: www.crisafulli.com

Standard Pump Inc
3230 Industrial Way
Snellville
GA 30039
USA
Tel: 770 972 9693
Fax: 770 972 9694
Email: info@standardpump.com
Web: www.standardpump.com

Sterling Fluid Systems (Americas) Inc
303 Industrial Boulevard
Grand Island
NY 14072-0460
USA
Tel: 716 773 6450
Fax: 716 773 2330
Email: mail@sihi.com
Web: www.sterlingfluid.com

Sundyne Corporation
14845 West 64th Avenue
Arvada
CO 80007
USA
Tel: 303 425 0800
Fax: 303 940 3141
Email: pumps@sundyne.com
Web: www.sundyne.com

Tarby Inc
2205 E L Anderson Boulevard
Claremore
OK 74017
USA
Tel: 918 341 8282
Fax: 918 341 8297
Email: sales@tarby.com
Web: www.tarby.com

Teledyne Isco Inc
PO Box 82531
Lincoln
NE 68501
USA
Tel: 4402 464 0231
Fax: 402 465 3064
Email: iscolinfo@teledyne.com
Web: www.isco.com

Thompson Pump & Manufacturing Co Inc
PO Box 291370
Port Orange
FL 32129-1370
USA
Tel: 800 767 7310

Fax: 386 761 0362
Email: sales@thompsonpump.com
Web: www.thompsonpumps.com

Trebor
 8100 South 1300 West
 West Jordan
 UT 84088
 USA
Tel: 801 561 0303
Fax: 801 255 2312
Email: treborsales@idexcorp.com
Web: www.treborintl.com

Tsurumi (America) Inc
 845 N. Dillon Drive
 Wood Dale
 IL 60191
 USA
Tel: 630 766 5900
Fax: 630 766 6445
Email: info@tsurumiamerica.com

Tuthill Corporation
 8500 South Madison
 Burr Ridge
 IL 60527
 USA
Tel: 630 382 4900
Fax: 630 382 4999
Email: tuthillpump@tuthill.com
Web: www.pump.tuthill.com

Vaughan Company Inc
 364 Monte Elma Road
 Montesano
 WA 98563
 USA
Tel: 360 249 4042
Fax: 360 149 6155
Email: info@chopperpumps.com
Web: www.chopperpumps.com

Versa-Matic Pump Company
 6017 Enterprise Drive
 Export
 PA 15632
 USA
Tel: 724 327 7867
Fax: 724 327 4300
Email: sales@versamatic.com
Web: www.versamatic.com

Vertiflo Pump Company
 Dept 1, 7807 Redsky Drive
 Cincinnati
 OH 45249
 USA
Tel: 513 530 0888
Fax: 513 530 0893
Email: sales@vertiflopump.com
Web: www.vertiflopump.com

Viking Pump Inc
 406 State Street
 PO Box 8
 Cedar Falls
 IA 50613-0008
 USA
Tel: 319 266 1741
Fax: 319 273 8157
Email: info.viking@idexcorp.com
Web: www.vikingpump.com

Warren Pumps LLC
 82 Bridges Avenue
 PO Box 969
 Warren
 MA 01083-0969
 USA
Tel: 413 436 7711
Fax: 413 436 5605
Email: warrensales@colfaxcorp.com
Web: www.warrenpumps.com

Warren Rupp Inc
 800 North Main Street
 PO Box 1568
 Mansfield
 OH 44901-1568
 USA
Tel: 419 524 8388
Fax: 419 522 7867
Email: info.warrenrupp@idexcorp.com
Web: www.warrenrupp.com

Waukesha Cherry-Burrell
 611 Sugar Creek Road
 Delavan
 WI 53115
 USA
Tel: 262 728 1900
Fax: 262 728 4904
Email: info@processequipment.spx.com
Web: www.gowcb.com

Weir Minerals Division
 225 N Cedar Street
 PO Box 488
 Hazelton
 PA 18201-0488
 USA
Tel: 717 455 7711
Fax: 717 459 2586
Email: pumps@weirminerals.com
Web: www.weirminerals.com

Weir Specialty Pumps
 440 West 800 South
 Salt Lake City
 UT 84110-0209
 USA
Tel: 801 359 8731
Fax: 801 355 9303
Email: info@wemcopump.com
Web: www.wemcopump.com

Wheatley and Gaso Pump
 PO Box 123
 Ada
 MI 49301
 USA
Tel: 616 452 6882
Fax: 888 796 2653
Email: info@wheatleygaso.com
Web: www.wheatleygaso.com

Wilden Pump & Engineering LLC
 22069 Van Buren Street
 Grand Terrace
 CA 92313-5607
 USA
Tel: 909 422 1730
Fax: 909 783 3440
Email: wilden@wildenpump.com
Web: www.wildenpump.com

A R Wilfley & Sons Inc
 PO Box 2330
 Denver
 CO 80201
 USA
Tel: 303 779 1777
Fax: 303 779 1277
Email: pumps@wilfley.com
Web: www.wilfley.com

Wright Pump
 S84 W18693 Enterprise Drive
 Muskego
 WI 53150
 USA
Tel: 262 679 8000
Fax: 262 679 2026
Email: info.wright@idexcorp.com
Web: www.softwavepumps.com

Yamada America Inc
 1200 Nuclear Drive, Dept I
 West Chicago
 IL 60185
 USA
Tel: 630 231 4083
Fax: 630 231 7398
Email: sales@yamadapump.com
Web: www.yamadapump.com

Yeomans Pump Company
 PO Box 6620
 Aurora
 IL 60598-0620
 USA
Tel: 630 236 5500
Fax: 630 236 5511
Email: donpage@yccpump.com
Web: www.yeomanspump.com

Zenith Pumps Division, Parker Hannifin
 5910 Elwin Buchanan Drive
 Sanford
 NC 27330
 USA
Tel: 919 7182225
Fax: 919 774 5952
Email: emmett.sellers@colfaxcorp.com
Web: www.zenithpumps.com

Zoeller Pump Company
 3649 Cane Run Road
 Louisville
 KY 40211-1961
 USA
Tel: 502 778 2731
Fax: 502 774 3624
Email: info@zoeller.com
Web: www.zoeller.com

VENEZUELA (VE)

Equimavenca
 Av Fernandez Padilla 226
 San José de Guanipa
 Edo Anzoategui
 Venezuela
Tel: 283 255 4830
Fax: 283 255 4830
Email: tchaline@pcmpompes.com
Web: www.pcmpompes.com

18.3 Rotodynamic pumps

Companies listed alphabetically by pump type

SMALL CENTRIFUGAL PUMPS

(for domestic water/heating/sanitation applications)

ABS Deutschland GmbH	DE	EMS Pacific	US	Rotex SA	GR
ABS Finland Oy	FI	FE Myers	US	Salmson Italia	IT
ABS France SAS	FR	Finder Pompe SpA	IT	Schmalenberger GmbH & Co	DE
ABS Group	SE	Flexachem Manufacturing Ltd	IE	Sharp Trendys	IN
ABS Hellas SA	GR	GMP SpA	IT	SHURflo Ltd	UK
ABS Hidrobomba SA	PL	Gorman-Rupp Company	US	SHURflo Pump Manufacturing Co	US
ABS Hungary Trading	HU	Goulds Pumps, ITT Industrial & BioPharm Group	US	Sigma Group AS	CZ
ABS Industria de Bombas Centrifugas Ltda	BR	Goulds Pumps, ITT Water Technology	US	Simaco Elettromeccanica Srl	IT
ABS International Srl	IT	Grundfos (Singapore) Pte Ltd	SG	Stuart Turner Ltd	UK
ABS Italy Srl	IT	Grundfos GmbH	DE	T Smedegaard A/S	DK
ABS Nopon Thai Co Ltd	TH	Grundfos Management A/S	DK	Tangshan Pump Factory	CN
ABS Oumoer A/S	NO	Grundfos Pompe Italia Srl	IT	3S Systemtechnik AG	CH
ABS PolskaSp. Z.o.o.	PL	Grundfos Pumpen Vertrieb GmbH	AT	TKL	AU
ABS Pompalari Ltd	TR	Grundfos Pumps Corporation	US	Torishima Pump Mfg Co Ltd	JP
ABS Pompen BV	NL	Grundfos Pumps KK	JP	Vertiflo Pump Company	US
ABS Pumpen GmbH	AT	Grundfos Pumps Ltd	UK	Wallace & Tiernan, Chemfeed Ltd	UK
ABS Pumps (Irl) Ltd	IE	Grundfos Pumps Pty Ltd	AU	Wilo AG	DE
ABS Pumps AS	EE	Handol Pumps Ltd	KR	Wilo EMU GmbH	DE
ABS Pumps Corporation	CA	Hayward Tyler® Group	UK	Zoeller Pump Company	US
ABS Pumps Inc	US	Herborner Pumpenfabrik	DE		
ABS Pumps Malaysia Sdn Bhd	MY	Honda Kiko Co Ltd	JP	DOMESTIC WATER SUPPLY PUMP PACKAGES	
ABS Pumps NV/SA	BE	Hunan XD Changsha Pump Works Co Ltd	CN	ACD Cryo GmbH	DE
ABS Shanghai Co Ltd	CN	Hyosung-Ebara Co Ltd	KR	Alpumps Ltd	UK
ABS Shanghai Co Ltd Beijing Liaison Office	CN	Invensys APV	US	APV Fluid Handling Horsens	DK
ABS Technologias del Agua SA	ES	Invensys APV UK	UK	Aurora Pump	US
ABS Wastewater Technology (Pty) Ltd	ZA	ITT Flygt AB	SE	Biral AG	CH
ABS Wastewater Technology Ltd	UK	ITT Residential & Commercial Water	US	Calama Industries Pvt Ltd	IN
ABS Wastewater Technology Pte Ltd	SG	Iwaki America	US	Calpeda SpA	IT
Alpumps Ltd	UK	Kielecka Fabryka Pomp Bialogon SA	PL	Camaction Avonpump Ltd	UK
APV Fluid Handling Horsens	DK	Klaus Union GmbH & Co KG	DE	Charles Austen Pumps Ltd	UK
Aurora Pump	US	Korina Pumps	GR	Circulating Pumps Ltd	UK
Beresford Pumps	UK	Leszno Pump Factory	PL	Clasal	BE
Biral AG	CH	Lewis Pumps	US	DAB Pumps SpA	IT
Bombas Itur SA	ES	Little Giant Pump Company	US	Darley Pumps	US
Calama Industries Pvt Ltd	IN	Lowara SpA, ITT Industries	IT	Davey Products Pty Ltd	AU
Calpeda SpA	IT	March May Ltd	UK	DDA Srl	IT
Caprari SpA	IT	Mark Grundfos Ltda	BR	Desmi A/S	DK
Carver Pump Company	US	Marlow Pumps, ITT Water Technology	US	DP-Pumps	NL
CAT Pumps	US	Marshall Engineered Products Company	US	Drakos-Polemis Inc	GR
CAT Pumps (UK) Ltd	UK	Matra SpA	IT	Ebara Corporation	JP
Ceetak Engineering Ltd	UK	Mepco	US	Ebara Fluid Handling	US
Charles Austen Pumps Ltd	UK	Motorarg SA	AR	Ebara Pumps Europe SpA	IT
Chempump	US	Nijhuis Pompen BV	NL	EDUR Pumpenfabrik GmbH & Co KG	DE
Chung Woo Industrial Co Ltd	KR	Nikkiso Co Ltd	JP	EMS Pacific	US
Circulating Pumps Ltd	UK	Nova Magnetis Burgmann Ltd	CA	Environamics Corporation	US
Clasal	BE	Nuovo Pignone	IT	Fairbanks Morse Pump	US
Cole-Parmer Instrument Company	US	Oddesse Pumpen-und Motorenfabrik GmbH	DE	FE Myers	US
Cougar Industries Ltd	UK	Pacer Pumps	US	Finder Pompe SpA	IT
DAB Pumps SpA	IT	Paco Pumps	US	Flexachem Manufacturing Ltd	IE
Davey Products Pty Ltd	AU	Peerless Pump Company	US	Goulds Pumps, ITT Industrial & BioPharm Group	US
DDA Srl	IT	Pompe Vergani	IT	Goulds Pumps, ITT Water Technology	US
Desmi A/S	DK	Power Pump Factory Co Ltd	PL	Grundfos (Singapore) Pte Ltd	SG
Discflo Corporation	US	Process Pumps (India) Pvt Ltd	IN	Grundfos GmbH	DE
DP-Pumps	NL	Pump & Package Ltd	UK	Grundfos Management A/S	DK
Drakos-Polemis Inc	GR	Pump Engineering Co Pvt Ltd	IN	Grundfos Pompe Italia Srl	IT
Ebara Corporation	JP	Pumpenfabrik Ernst Vogel GmbH, ITT Industries	AT	Grundfos Pumpen Vertrieb GmbH	AT
Ebara Fluid Handling	US	Raj Pumps	IN	Grundfos Pumps Corporation	US
Ebara Pumps Europe SpA	IT	Rapid Allweiler Pump & Engineering	ZA	Grundfos Pumps KK	JP
EDUR Pumpenfabrik GmbH & Co KG	DE	Red Jacket, ITT Water Technology	US	Grundfos Pumps Ltd	UK
		Ritz Pumpenfabrik GmbH & Co KG	DE	Grundfos Pumps Pty Ltd	AU

Handol Pumps Ltd	KR	Grundfos Pumps KK	JP	Grundfos Pumpen Vertrieb GmbH	AT
Honda Kiko Co Ltd	JP	Grundfos Pumps Ltd	UK	Grundfos Pumps Corporation	US
Hyosung-Ebara Co Ltd	KR	Grundfos Pumps Pty Ltd	AU	Grundfos Pumps KK	JP
Invensys APV	US	Hale Products Europe Ltd	UK	Grundfos Pumps Ltd	UK
Invensys APV UK	UK	Handol Pumps Ltd	KR	Grundfos Pumps Pty Ltd	AU
ITT Flygt AB	SE	Herborner Pumpenfabrik	DE	Handol Pumps Ltd	KR
ITT Residential & Commercial Water	US	Honda Kiko Co Ltd	JP	Herborner Pumpenfabrik	DE
Kielecka Fabryka Pomp Bialogon SA	PL	Hyosung-Ebara Co Ltd	KR	Hilge Pumps Ltd	UK
Lowara SpA, ITT Industries	IT	Kelair Pumps Australia Pty Ltd	AU	Honda Kiko Co Ltd	JP
Mark Grundfos Ltda	BR	Lowara SpA, ITT Industries	IT	Hyosung-Ebara Co Ltd	KR
Marshall Engineered Products Company	US	Mark Grundfos Ltda	BR	ITT Flygt AB	SE
Mepco	US	Nasosenergomash	UA	ITT Residential & Commercial Water	US
Nijhuis Pompen BV	NL	Nijhuis Pompen BV	NL	Jiangsu Haishi Pump Co Ltd	CN
Nuovo Pignone	IT	Ohler Pumps	US	Kelair Pumps Australia Pty Ltd	AU
Oy Kolmeks AB	FI	Paco Pumps	US	KSB Ltd	UK
Paco Pumps	US	Patterson Pump Company	US	Laxmi Hydraulics Pvt Ltd	IN
Patterson Pump Company	US	Peerless Pump Company	US	Lowara SpA, ITT Industries	IT
Peerless Pump Company	US	Pompe Garbarino SpA	IT	Mark Grundfos Ltda	BR
Pompe Garbarino SpA	IT	Powen Pump Factory Co Ltd	PL	Mefiag Division, Met-Pro Corporation	US
Powen Pump Factory Co Ltd	PL	Pump & Package Ltd	UK	Nijhuis Pompen BV	NL
Pump & Package Ltd	UK	Pump Engineering Ltd	UK	Nuovo Pignone	IT
Pumpenfabrik Ernst Vogel GmbH, ITT Industries	AT	Ritz Pumpenfabrik GmbH & Co KG	DE	Ohler Pumps	US
Raj Pumps	IN	Rovatti Pompe	IT	Pacer Pumps	US
Rapid Allweiler Pump & Engineering	ZA	Ruhrpumpen GmbH	DE	Paco Pumps	US
Red Jacket, ITT Water Technology	US	Ruhrpumpen Inc	US	Peerless Pump Company	US
Ritz Pumpenfabrik GmbH & Co KG	DE	Stuart Turner Ltd	UK	Pompe Garbarino SpA	IT
Ruhrpumpen GmbH	DE	TKL	AU	Powen Pump Factory Co Ltd	PL
Ruhrpumpen Inc	US	Verder Group	NL	Pump & Package Ltd	UK
Sero PumpSystems GmbH	DE	Willy Vogel AG	DE	Pumpenfabrik Ernst Vogel GmbH, ITT Industries	AT
Stuart Turner Ltd	UK	Wilo AG	DE	Red Jacket, ITT Water Technology	US
TKL	AU	Wilo EMU GmbH	DE	Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA
Torishima Pump Mfg Co Ltd	JP	HORIZONTAL SINGLE-STAGE END-SUCTION OVERHUNG IMPELLER CENTRIFUGAL PUMPS (for general purposes including fixed irrigation & EN 733 pumps)		Ritz Pumpenfabrik GmbH & Co KG	DE
Wilo AG	DE			Roto Pumps Ltd	IN
Wilo EMU GmbH	DE			Rovatti Pompe	IT
SMALL CENTRIFUGAL PUMPS (for machine tool cutting oil applications)		Allweiler AG	DE	Ruhrpumpen GmbH	DE
		Best & Crompton Engineering Ltd	IN	Ruhrpumpen Inc	US
		Camaction Avonpump Ltd	UK	Savino Barbera	IT
		Caprari SpA	IT	Sethco Division, Met-Pro Corporation	US
ACD Cryo GmbH	DE	Carver Pump Company	US	SPP Pumps Ltd	UK
Biral AG	CH	Crane Pumps & Systems	US	Sterling Fluid Systems (Americas) Inc	US
Bombas Itur SA	ES	DAB Pumps SpA	IT	Sterling Fluid Systems (Austria)	AT
Camaction Avonpump Ltd	UK	Dalian Danai Pumps Ltd	CN	Sterling Fluid Systems (Belgium) NV	BE
Carver Pump Company	US	Darley Pumps	US	Sterling Fluid Systems (France) SAS	FR
Crane Pumps & Systems	US	Dean Pump Division, Met-Pro Corporation	US	Sterling Fluid Systems (Italy) SpA	IT
DAB Pumps SpA	IT	Desmi A/S	DK	Sterling Fluid Systems (Netherlands)	NL
Desmi A/S	DK	Ebara Corporation	JP	Sterling Fluid Systems (Schweiz) AG	CH
DP-Pumps	NL	Ebara Fluid Handling	US	Sterling Fluid Systems (UK) Ltd	UK
Ebara Corporation	JP	Ebara Pumps Europe SpA	IT	Sterling SIHI GmbH	DE
EDUR Pumpenfabrik GmbH & Co KG	DE	EDUR Pumpenfabrik GmbH & Co KG	DE	Tianjin Pumps & Machinery Group Co Ltd	CN
Emile Egger et Cie SA	CH	Emile Egger et Cie SA	CH	TKL	AU
Environamics Corporation	US	Engineered Products Group Pty Ltd (EPG)	AU	Ture International Industrial Ltd	CN
Fairbanks Morse Pump	US	Environamics Corporation	US	Verder Group	NL
FE Myers	US	Fairbanks Morse Pump	US	Victor Pumpen GmbH	DE
Finish Thompson Inc	US	FE Myers	US	Weir Pumps Ltd	UK
Flexachem Manufacturing Ltd	IE	Finish Thompson Inc	US	Wilo AG	DE
Flowmore Private Ltd	IN	Flexachem Manufacturing Ltd	IE	Wilo EMU GmbH	DE
Gilbert Gilkes & Gordon Ltd	UK	Flowserve Corporation	US	HORIZONTAL SINGLE-STAGE END-SUCTION OVERHUNG IMPELLER CENTRIFUGAL PUMPS (for chemical applications including ISO 2858, ISO 3069, ISO 3661, ASME/ANSI B73.1 designs)	
Gorman-Rupp Company	US	Goulds Pumps,	US		
Goulds Pumps,	US	ITT Industrial & BioPharm Group	SG		
ITT Industrial & BioPharm Group	US	Goulds Pumps, ITT Water Technology	US		
Grundfos (Singapore) Pte Ltd	SG	Grundfos (Singapore) Pte Ltd	SG	ACD Cryo GmbH	DE
Grundfos GmbH	DE	Grundfos GmbH	DE	ACD Inc	US
Grundfos Management A/S	DK	Grundfos Management A/S	DK	Ace Pump Corporation	US
Grundfos Pompe Italia Srl	IT	Grundfos Pompe Italia Srl	IT		
Grundfos Pumpen Vertrieb GmbH	AT				
Grundfos Pumps Corporation	US				

[illegible]

Verder Group	NL	Shanghai Liansheng Pump Manufacture Co Ltd	CN	Ruhrpumpen GmbH	DE
Vertiflo Pump Company	US	SRS Crisafulli Inc	US	Ruhrpumpen Inc	US
Weir Gabbioneta Srl	IT	Sulzer Pumps	CH	Sacem SpA	IT
Weir Pumps Ltd	UK	Taiko Kikai Industries Co Ltd	JP	Shanghai Liansheng Pump Manufacture Co Ltd	CN
WPIL Ltd	IN	Tangshan Pump Factory	CN	SPP Pumps Ltd	UK
HORIZONTAL SINGLE-STAGE DOUBLE-SUCTION AXIALLY-SPLIT PUMPS		TKL	AU	Sulzer Pumps	CH
(for general purposes)		Ture International Industrial Ltd	CN	Taiko Kikai Industries Co Ltd	JP
Argal Srl	IT	Volta Ltd	IN	Tangshan Pump Factory	CN
Gruppo Aturia SpA	IT	Weir Pumps Ltd	UK	Tianjin Pumps & Machinery Group Co Ltd	CN
Aurora Pump	US	HORIZONTAL SINGLE-STAGE DOUBLE-SUCTION AXIALLY-SPLIT PUMPS		TKL	AU
Charles Austen Pumps Ltd	UK	(for heavy-duty applications including ISO 13709, API 610 designs)		Ture International Industrial Ltd	CN
Best & Crompton Engineering Ltd	IN	Gruppo Aturia SpA	IT	United Pumps Australia (UPA)	AU
Biral AG	CH	CDS-John Blue Company	US	Volta Ltd	IN
Buffalo Pumps Inc	US	Concentric Pumps Ltd	UK	Weir Gabbioneta Srl	IT
Chem Resist Group Ltd	UK	Corporacion EG SA	MX	Weir Pumps Ltd	UK
Crane Pumps & Systems	US	Dalian Danai Pumps Ltd	CN	HORIZONTAL TWO-STAGE END-SUCTION OVERHUNG IMPELLER CENTRIFUGAL PUMPS	
Dalian Danai Pumps Ltd	CN	Debem	IT	Ace Pump Corporation	US
Darley Pumps	US	Desmi A/S	DK	Albany Engineering Company Ltd	UK
Drakos-Polemis Inc	GR	Ebara Corporation	JP	Allweiler AG	DE
Ebara Corporation	JP	Ebara Fluid Handling	US	Aurora Pump	US
EDUR Pumpenfabrik GmbH & Co KG	DE	Ebara Pumps Europe SpA	IT	Beresford Pumps	UK
Emile Egger et Cie SA	CH	EDUR Pumpenfabrik GmbH & Co KG	DE	Biral AG	CH
Franz Eisele und Söhne GmbH & Co KG	DE	Emile Egger et Cie SA	CH	Buffalo Pumps Inc	US
Engineered Products Group Pty Ltd (EPG)	AU	Engineered Products Group Pty Ltd (EPG)	AU	Calpeda SpA	IT
Flexachem Manufacturing Ltd	IE	Ensival-Moret	BE	Camaction Avonpump Ltd	UK
Flowmore Private Ltd	IN	Flexachem Manufacturing Ltd	IE	Caprari SpA	IT
Flowserve Corporation	US	Flojet Corporation	US	Casals Cardona Industries SA	ES
Goulds Pumps, ITT Industrial & BioPharm Group	US	Flowmore Private Ltd	IN	CDR Pompe SpA	IT
Grundfos (Singapore) Pte Ltd	SG	Flowserve Corporation	US	Ceetak Engineering Ltd	UK
Grundfos GmbH	DE	Goulds Pumps, ITT Industrial & BioPharm Group	US	Chempump	US
Grundfos Management A/S	DK	Grundfos (Singapore) Pte Ltd	SG	Chemvac Pumps Ltd	UK
Grundfos Pompe Italia Srl	IT	Grundfos GmbH	DE	Chicago Pump Company	US
Grundfos Pumpen Vertrieb GmbH	AT	Grundfos Management A/S	DK	Cougar Industries Ltd	UK
Grundfos Pumps Corporation	US	Grundfos Pompe Italia Srl	IT	Crane Pumps & Systems	US
Grundfos Pumps KK	JP	Grundfos Pumpen Vertrieb GmbH	AT	Crest Pumps Ltd	UK
Grundfos Pumps Ltd	UK	Grundfos Pumps Corporation	US	Pompe Cucchi Srl	IT
Grundfos Pumps Pty Ltd	AU	Grundfos Pumps KK	JP	Dalian Danai Pumps Ltd	CN
Hale Products Europe Ltd	UK	Grundfos Pumps Ltd	UK	Davey Products Pty Ltd	AU
Handol Pumps Ltd	KR	Grundfos Pumps Pty Ltd	AU	DDA Srl	IT
Honda Kiko Co Ltd	JP	Hale Products Europe Ltd	UK	Desmi A/S	DK
Hyosung-Ebara Co Ltd	KR	Handol Pumps Ltd	KR	Ebara Corporation	JP
ITT Flygt AB	SE	Honda Kiko Co Ltd	JP	Ebara España Bombas SA	ES
ITT Residential & Commercial Water	US	Hyosung-Ebara Co Ltd	KR	EBS-Ray Pumps Pty Ltd	AU
Kelair Pumps Australia Pty Ltd	AU	Jiangsu Haishi Pump Co Ltd	CN	EDUR Pumpenfabrik GmbH & Co KG	DE
KSB Ltd	UK	Kelair Pumps Australia Pty Ltd	AU	Emile Egger et Cie SA	CH
Mark Grundfos Ltda	BR	Leszno Pump Factory	PL	Engineered Products Group Pty Ltd (EPG)	AU
FE Myers	US	Magnatex Pumps Inc	US	Environamics Corporation	US
Nasosenergomash	UA	Mark Grundfos Ltda	BR	Fairbanks Morse Pump	US
Nijhuis Pompen BV	NL	Micropump Ltd	UK	Fapmo	FR
Nuovo Pignone	IT	MP Pumps Inc	US	Finish Thompson Inc	US
Ohler Pumps	US	FE Myers	US	Flexachem Manufacturing Ltd	IE
Paco Pumps	US	Nasosenergomash	UA	Flowmore Private Ltd	IN
Peerless Pump Company	US	Nijhuis Pompen BV	NL	Flowserve Corporation	US
Power Pump Factory Co Ltd	PL	Packo Inox NV	BE	Gilbert Gilkes & Gordon Ltd	UK
PT Ebara Indonesia	ID	Paco Pumps	US	Goulds Pumps, ITT Industrial & BioPharm Group	US
Pump & Package Ltd	UK	Peerless Pump Company	US	Arthur Habermann GmbH & Co KG	DE
Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA	Power Pump Factory Co Ltd	PL	Handol Pumps Ltd	KR
Ritz Pumpenfabrik GmbH & Co KG	DE	Pump & Package Ltd	UK	Hermetic-Pumpen GmbH	DE
Roto Pumps Ltd	IN	Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA	Honda Kiko Co Ltd	JP
Rovatti Pompe	IT	Ritz Pumpenfabrik GmbH & Co KG	DE	Hunan XD Changsha Pump Works Co Ltd	CN
Ruhrpumpen GmbH	DE	Rovatti Pompe	IT	Hyosung-Ebara Co Ltd	KR
Ruhrpumpen Inc	US			ITT Residential & Commercial Water	US

Iwaki America	US	EMS Pacific	US	Sterling SIHI GmbH	DE
Johnson Pump (India), ATE Enterprises Ltd	IN	Engineered Products Group Pty Ltd (EPG)	AU	Termomeccanica Pompe SpA	IT
Johnson Pump AB	SE	FE Myers	US	TKL	AU
Johnson Pump BV	NL	Flexachem Manufacturing Ltd	IE	Toyo Pumps Europe	BE
Johnson Pumps of America Inc	US	Flowmore Private Ltd	IN	Ture International Industrial Ltd	CN
Kelair Pumps Australia Pty Ltd	AU	Flowserve Corporation	US	Verder Group	NL
Oy Kolmeks AB	FI	Goulds Pumps,	US	Weir Pumps Ltd	UK
KSB Ltd	UK	ITT Industrial & BioPharm Group			
London Pumps Ltd	UK	Grundfos (Singapore) Pte Ltd	SG	VERTICAL SINGLE-STAGE OVERHUNG IMPELLER CENTRIFUGAL PUMPS (for chemical applications including ASME/ANSI B73.2 designs)	
Magnatex Pumps Inc	US	Grundfos GmbH	DE		
Marshall Engineered Products Company	US	Grundfos Management A/S	DK	ACD Cryo GmbH	DE
Matra SpA	IT	Grundfos Pompe Italia Srl	IT	ACD Inc	US
Mepco	US	Grundfos Pumpen Vertrieb GmbH	AT	Allpumps Ltd	UK
MP Pumps Inc	US	Grundfos Pumps Corporation	US	APV Fluid Handling Horsens	DK
MTH Pumps	US	Grundfos Pumps KK	JP	Argal Srl	IT
FE Myers	US	Grundfos Pumps Ltd	UK	Best & Crompton Engineering Ltd	IN
Nasosenergomash	UA	Grundfos Pumps Pty Ltd	AU	Biral AG	CH
Nijhuis Pompen BV	NL	Gzut SA Pumps Department	PL	Cakasa (Nigeria) Co Ltd	NG
Paco Pumps	US	Handol Pumps Ltd	KR	Camaction Avonpump Ltd	UK
Pedrollo SpA	IT	Hayward Tyler® Group	UK	Caster HMD Kontro	UK
Peerless Pump Company	US	Hermetic-Pumpen GmbH	DE	Charles Austen Pumps Ltd	UK
Power Pump Factory Co Ltd	PL	Honda Kiko Co Ltd	JP	Concentric Pumps Ltd	UK
Process Pumps (India) Pvt Ltd	IN	Hyosung-Ebara Co Ltd	KR	Corporacion EG SA	MX
Pump & Package Ltd	UK	Invensys APV	US	Cougar Industries Ltd	UK
Pump Engineering Ltd	UK	Invensys APV UK	UK	Crest Pumps Ltd	UK
Reddy-Buffaloes Pump Inc	US	ITT Flygt AB	SE	Dalian Danai Pumps Ltd	CN
Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA	ITT Residential & Commercial Water	US	Dean Pump Division, Met-Pro Corporation	US
Ritz Pumpenfabrik GmbH & Co KG	DE	Iwaki Co Ltd	JP	Desmi A/S	DK
Roto Pumps Ltd	IN	Iwaki Europe GmbH	DE	Dickow Pumpen KG	DE
Rovatti Pompe	IT	Kelair Pumps Australia Pty Ltd	AU	Drakos-Polemis Inc	GR
Ruhrpumpen GmbH	DE	Kestner Engineering Co Ltd	UK	Ebara Corporation	JP
Ruhrpumpen Inc	US	Kielecka Fabryka Pomp Bialogon SA	PL	EDUR Pumpenfabrik GmbH & Co KG	DE
Rütschi Fluid AG	CH	KSB Ltd	UK	Emile Egger et Cie SA	CH
Saer Elektropompe	IT	Lowara SpA, ITT Industries	IT	EMS Pacific	US
Shanghai Liansheng Pump Manufacture Co Ltd	CN	Magnatex Pumps Inc	US	Engineered Products Group Pty Ltd (EPG)	AU
Slovopump-Trade Sro	SK	Mark Grundfos Ltda	BR	Ensival-Moret	BE
Michael Smith Engineers Ltd	UK	Nijhuis Pompen BV	NL	Environamics Corporation	US
Speck-Pumpen	DE	Oy Kolmeks AB	FI	FE Myers	US
SPP Pumps Ltd	UK	Packo Inox NV	BE	Flexachem Manufacturing Ltd	IE
Sulzer Pumps	CH	Paco Pumps	US	Flowmore Private Ltd	IN
Swidnicka Fabryka Pomp Sp Z.o.o.	PL	Peerless Pump Company	US	Flowserve Corporation	US
TKL	AU	Pompe Garbarino SpA	IT	Goulds Pumps,	US
Vertiflo Pump Company	US	Power Pump Factory Co Ltd	PL	ITT Industrial & BioPharm Group	
Pumpenfabrik Ernst Vogel GmbH, ITT Industries	AT	Pump & Package Ltd	UK	Gruppo Aturia SpA	IT
		Pumpenfabrik Ernst Vogel GmbH, ITT Industries	AT	Gzut SA Pumps Department	PL
		Raj Pumps	IN	Handol Pumps Ltd	KR
		Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA	Hayward Tyler® Group	UK
		Ritz Pumpenfabrik GmbH & Co KG	DE	Hermetic-Pumpen GmbH	DE
		Rovatti Pompe	IT	Hilge Pumps Ltd	UK
		Ruhrpumpen GmbH	DE	Honda Kiko Co Ltd	JP
		Ruhrpumpen Inc	US	Hyosung-Ebara Co Ltd	KR
		Savino Barbera	IT	Invensys APV	US
		Sethco Division, Met-Pro Corporation	US	Invensys APV UK	UK
		Shanghai Liansheng Pump Manufacture Co Ltd	CN	Iwaki Co Ltd	JP
		Speck-Pumpen	DE	Iwaki Europe GmbH	DE
		SPP Pumps Ltd	UK	Jiangsu Haishi Pump Co Ltd	CN
		Sterling Fluid Systems (Americas) Inc	US	Kelair Pumps Australia Pty Ltd	AU
		Sterling Fluid Systems (Austria)	AT	Kestner Engineering Co Ltd	UK
		Sterling Fluid Systems (Belgium) NV	BE	Kishor Pumps Ltd	IN
		Sterling Fluid Systems (France) SAS	FR	Laxmi Hydraulics Pvt Ltd	IN
		Sterling Fluid Systems (Italy) SpA	IT	March May Ltd	UK
		Sterling Fluid Systems (Netherlands)	NL	Marshall Engineered Products Company	US
		Sterling Fluid Systems (Schweiz) AG	CH	MASO Process-Pumpen GmbH	DE
		Sterling Fluid Systems (UK) Ltd	UK	Mepco	US
				Michael Smith Engineers Ltd	UK
VERTICAL SINGLE-STAGE OVERHUNG IMPELLER CENTRIFUGAL PUMPS (for general applications)					
		Allpumps Ltd	UK		
		Allweiler AG	DE		
		APV Fluid Handling Horsens	DK		
		Aurora Pump	US		
		Biral AG	CH		
		Camaction Avonpump Ltd	UK		
		Caprari SpA	IT		
		Charles Austen Pumps Ltd	UK		
		Corporacion EG SA	MX		
		Dalian Danai Pumps Ltd	CN		
		Dean Pump Division, Met-Pro Corporation	US		
		Desmi A/S	DK		
		Drakos-Polemis Inc	GR		
		Ebara Corporation	JP		
		Ebara España Bombas SA	ES		
		EDUR Pumpenfabrik GmbH & Co KG	DE		
		Emile Egger et Cie SA	CH		

Micropump Ltd	UK	Grundfos Pumpen Vertrieb GmbH	AT	ABS Italy Srl	IT
MP Pumps Inc	US	Grundfos Pumps Corporation	US	ABS Nopon Thai Co Ltd	TH
Nijhuis Pompen BV	NL	Grundfos Pumps KK	JP	ABS Oumoer A/S	NO
Nova Magnetics Burgmann Ltd	CA	Grundfos Pumps Ltd	UK	ABS PolskaSp. Z.o.o.	PL
Paco Pumps	US	Grundfos Pumps Pty Ltd	AU	ABS Pompalari Ltd	TR
Peerless Pump Company	US	Handol Pumps Ltd	KR	ABS Pompen BV	NL
Pumpenfabrik Ernst Vogel GmbH, ITT Industries	IT	Honda Kiko Co Ltd	JP	ABS Pumpen GmbH	AT
Power Pump Factory Co Ltd	PL	Hyosung-Ebara Co Ltd	KR	ABS Pumps (Irl) Ltd	IE
PPI Pumps Pvt Ltd	IN	Invensys APV	US	ABS Pumps AS	EE
Pulsafeeder	US	Invensys APV UK	UK	ABS Pumps Corporation	CA
Pump & Package Ltd	UK	ITT Flygt AB	SE	ABS Pumps Inc	US
Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA	ITT Residential & Commercial Water	US	ABS Pumps Malaysia Sdn Bhd	MY
Ritz Pumpenfabrik GmbH & Co KG	DE	Iwaki Co Ltd	JP	ABS Pumps NV/SA	BE
Rovatti Pompe	IT	Iwaki Europe GmbH	DE	ABS Shanghai Co Ltd	CN
Ruhrpumpen GmbH	DE	Kelair Pumps Australia Pty Ltd	AU	ABS Shanghai Co Ltd Beijing Liaison Office	CN
Ruhrpumpen Inc	US	Oy Kolmeks AB	FI	ABS Tecnologias del Agua SA	ES
Savino Barbera	IT	KSB Ltd	UK	ABS Wastewater Technology (Pty) Ltd	ZA
Sero PumpSystems GmbH	DE	Landini Fabbrica Pompe Centrifughe Srl	IT	ABS Wastewater Technology Ltd	UK
Shanghai Liansheng Pump Manufacture Co Ltd	CN	Lowara SpA, ITT Industries	IT	ABS Wastewater Technology Pte Ltd	SG
Shanxi Jishan Qinglong Pump Industry Co Ltd	CN	Mark Grundfos Ltda	BR	Alfons de Backer & Co	BE
Simaco Elettromeccanica Srl	IT	Mather & Platt Pumps Ltd	IN	Allweiler AG	DE
Siwatec AS	CZ	FE Myers	US	Batescrew Pumps	AU
Sterling Fluid Systems (Americas) Inc	US	Nijhuis Pompen BV	NL	Biral AG	CH
Sterling Fluid Systems (Austria)	AT	Paco Pumps	US	Ceetak Engineering Ltd	UK
Sterling Fluid Systems (Belgium) NV	BE	Patterson Pump Company	US	Chung Woo Industrial Co Ltd	KR
Sterling Fluid Systems (France) SAS	FR	Peerless Pump Company	US	DAB Pumps SpA	IT
Sterling Fluid Systems (Italy) SpA	IT	Power Pump Factory Co Ltd	PL	Davey Products Pty Ltd	AU
Sterling Fluid Systems (Netherlands)	NL	Pump & Package Ltd	UK	Dempster Industries Inc	US
Sterling Fluid Systems (Schweiz) AG	CH	Raj Pumps	IN	Eagle Pump & Compressor Ltd	CA
Sterling Fluid Systems (UK) Ltd	UK	Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA	Ebara Corporation	JP
Sterling SIHI GmbH	DE	Ritz Pumpenfabrik GmbH & Co KG	DE	EDUR Pumpenfabrik GmbH & Co KG	DE
Sundyne Corporation	US	Rovatti Pompe	IT	Emile Egger et Cie SA	CH
Sundyne International SA	FR	Ruhrpumpen GmbH	DE	Engineered Products Group Pty Ltd (EPG)	AU
Tangshan Pump Factory	CN	Ruhrpumpen Inc	US	Ensival-Moret	BE
Termomeccanica Pompe SpA	IT	Saer Elettropompe	IT	Finder Pompe SpA	IT
TKL	AU	Shanghai Liansheng Pump Manufacture Co Ltd	CN	Flexachem Manufacturing Ltd	IE
Türbosan AS	TR	Speck-Pumpen	DE	Flowmore Private Ltd	IN
Ture International Industrial Ltd	CN	Sterling Fluid Systems (Americas) Inc	US	Flowserve Corporation	US
VERTICAL MULTI-STAGE CENTRIFUGAL PUMPS (for general applications including segmental pumps, dH <300 m, deep well ejector applications, wash water)		Sterling Fluid Systems (Austria)	AT	Goulds Pumps, ITT Industrial & BioPharm Group	US
Aker Kvaerner Eureka Pump Systems	NO	Sterling Fluid Systems (Belgium) NV	BE	Handol Pumps Ltd	KR
Allpumps Ltd	UK	Sterling Fluid Systems (France) SAS	FR	Hayward Tyler® Group	UK
APV Fluid Handling Horsens	DK	Sterling Fluid Systems (Italy) SpA	IT	Hidrostal Ltd	UK
Best & Crompton Engineering Ltd	IN	Sterling Fluid Systems (Netherlands)	NL	Honda Kiko Co Ltd	JP
Caprari SpA	IT	Sterling Fluid Systems (Schweiz) AG	CH	Hyosung-Ebara Co Ltd	KR
Chempump	US	Sterling Fluid Systems (UK) Ltd	UK	ITT Flygt AB	SE
DP-Pumps	NL	Sterling SIHI GmbH	DE	Johnston Pump	US
Düchting Pumpen Maschinenfabrik GmbH	DE	TKL	AU	Kelair Pumps Australia Pty Ltd	AU
Ebara Corporation	JP	Torishima Pump Mfg Co Ltd	JP	KSB Ltd	UK
EDUR Pumpenfabrik GmbH & Co KG	DE	Türbosan AS	TR	Landini Fabbrica Pompe Centrifughe Srl	IT
Emile Egger et Cie SA	CH	Ture International Industrial Ltd	CN	Lederle GmbH	DE
EMS Pacific	US	United Pumps Australia (UPA)	AU	Megator Ltd	UK
Engineered Products Group Pty Ltd (EPG)	AU	Verder Group	NL	Melotte Pumptechnology BV	NL
Flexachem Manufacturing Ltd	IE	Pumpenfabrik Ernst Vogel GmbH, ITT Industries	AT	Metso Minerals (Sala) AB	SE
Flowmore Private Ltd	IN	VERTICAL WET-PIT PUMPS		Moyno Inc	US
Flowserve Corporation	US	ABS Deutschland GmbH	DE	FE Myers	US
Goulds Pumps, ITT Industrial & BioPharm Group	US	ABS Finland Oy	FI	National Pump Company LLC	US
Grundfos (Singapore) Pte Ltd	SG	ABS France SAS	FR	Nijhuis Pompen BV	NL
Grundfos GmbH	DE	ABS Group	SE	Paco Pumps	US
Grundfos Management A/S	DK	ABS Hellas SA	GR	Peerless Pump Company	US
Grundfos Pompe Italia Srl	IT	ABS Hidrobomba SA	PL	PEME-Gourdin SA	FR
		ABS Hungary Trading	HU	Pumpenfabrik Ernst Vogel GmbH, ITT Industries	IT
		ABS Industria de Bombas Centrifugas Ltda	BR	Power Pump Factory Co Ltd	PL
		ABS International Srl	IT	Pump & Package Ltd	UK
				Pumpenfabrik Wangen GmbH	DE

Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA	Engineered Products Group Pty Ltd (EPG)	AU	EDUR Pumpenfabrik GmbH & Co KG	DE
Ritz Pumpenfabrik GmbH & Co KG	DE	Ensival-Moret	BE	Emile Egger et Cie SA	CH
Rovatti Pompe	IT	FE Myers	US	Flowserve Corporation	US
Ruhrpumpen GmbH	DE	Finder Pompe SpA	IT	Gorman-Rupp Company	US
Ruhrpumpen Inc	US	Flexachem Manufacturing Ltd	IE	Goulds Pumps,	US
Savino Barbera	IT	Flowmore Private Ltd	IN	ITT Industrial & BioPharm Group	
Shanxi Jishan Qinglong Pump Industry Co Ltd	CN	Flowserve Corporation	US	Gzut SA Pumps Department	PL
Shijiazhuang Pump Industry Group Co Ltd	CN	Gilbert Gilkes & Gordon Ltd	UK	Hamworthy KSE	UK
Sigma Group AS	CZ	Goulds Pumps,	US	Hamworthy Svanehøj A/S	DK
Sulzer Pumps	CH	ITT Industrial & BioPharm Group		Jabsco GmbH, ITT Industries	DE
TKL	AU	Grundfos (Singapore) Pte Ltd	SG	Jabsco UK, ITT Industries	UK
Türbosan AS	TR	Grundfos GmbH	DE	Jabsco US, ITT Industries	US
Tyco - Southern Cross Plant	AU	Grundfos Management A/S	DK	Johnson Pump (India), ATE Enterprises Ltd	IN
Vaughan Company Inc	US	Grundfos Pompe Italia Srl	IT	Johnson Pump AB	SE
Pumpenfabrik Ernst Vogel GmbH,	AT	Grundfos Pumpen Vertrieb GmbH	AT	Johnson Pump BV	NL
ITT Industries		Grundfos Pumps Corporation	US	Johnson Pumps of America Inc	US
Voltas Ltd	IN	Grundfos Pumps KK	JP	Megator Ltd	UK
Warren Pumps LLC	US	Grundfos Pumps Ltd	UK	Frank Mohn AS	NO
Weir Pumps Ltd	UK	Grundfos Pumps Pty Ltd	AU	FE Myers	US
Wernert-Pumpen GmbH	DE	Handol Pumps Ltd	KR	Pentair Inc	US
Wilo AG	DE	Hidrostal Ltd	UK	Pentair Pumps SpA	IT
Wilo EMU GmbH	DE	Honda Kiko Co Ltd	JP	Rapid Allweiler Pump & Engineering	ZA
Worthington SpA	IT	Hunan XD Changsha Pump Works Co Ltd	CN	Sethco Division, Met-Pro Corporation	US
WPIL Ltd	IN	Hyosung-Ebara Co Ltd	KR	Shin Shin Machinery Co Ltd	KR
Yeomans Pump Company	US	ITT Flygt AB	SE	Sigma Group AS	CZ
VERTICAL DRY-PIT PUMPS		Kelair Pumps Australia Pty Ltd	AU	Smith & Loveless Inc	US
ABS Deutschland GmbH	DE	Landini Fabbria Pompe Centrifughe Srl	IT	Sterling Fluid Systems (Americas) Inc	US
ABS Finland Oy	FI	Mark Grundfos Ltda	BR	Sterling Fluid Systems (Austria)	AT
ABS France SAS	FR	Mather & Platt Pumps Ltd	IN	Sterling Fluid Systems (Belgium) NV	BE
ABS Group	SE	Megator Ltd	UK	Sterling Fluid Systems (France) SAS	FR
ABS Hellas SA	GR	Nijhuis Pompen BV	NL	Sterling Fluid Systems (Italy) SpA	IT
ABS Hidrobomba SA	PL	Paco Pumps	US	Sterling Fluid Systems (Netherlands)	NL
ABS Hungary Trading	HU	Peerless Pump Company	US	Sterling Fluid Systems (Schweiz) AG	CH
ABS Industria de Bombas Centrifugas Ltda	BR	Pumpenfabrik Ernst Vogel GmbH,	IT	Sterling Fluid Systems (UK) Ltd	UK
ABS International Srl	IT	ITT Industries		Sterling SIHI GmbH	DE
ABS Italy Srl	IT	Powen Pump Factory Co Ltd	PL	TKL	AU
ABS Nopon Thai Co Ltd	TH	Pump & Package Ltd	UK	Tycon Alloy Industries (Hong Kong) Co Ltd	HK
ABS Oumoer A/S	NO	Pump Engineering Co Pvt Ltd	IN	Vaughan Company Inc	US
ABS PolskaSp. Z.o.o.	PL	Pumpenfabrik Ernst Vogel GmbH,	AT	Weir Pumps Ltd	UK
ABS Pompalari Ltd	TR	ITT Industries		SUBMERSIBLE PUMPS WITH ELECTRIC MOTOR	
ABS Pompen BV	NL	Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA	ABS Deutschland GmbH	DE
ABS Pumpen GmbH	AT	Ritz Pumpenfabrik GmbH & Co KG	DE	ABS Finland Oy	FI
ABS Pumps (Irl) Ltd	IE	Rovatti Pompe	IT	ABS France SAS	FR
ABS Pumps AS	EE	Ruhrpumpen GmbH	DE	ABS Group	SE
ABS Pumps Corporation	CA	Ruhrpumpen Inc	US	ABS Hellas SA	GR
ABS Pumps Inc	US	Sigma Group AS	CZ	ABS Hidrobomba SA	PL
ABS Pumps Malaysia Sdn Bhd	MY	Speck-Pumpen	DE	ABS Hungary Trading	HU
ABS Pumps NV/SA	BE	Taiko Kikai Industries Co Ltd	JP	ABS Industria de Bombas Centrifugas Ltda	BR
ABS Shanghai Co Ltd	CN	Termomeccanica Pompe SpA	IT	ABS International Srl	IT
ABS Shanghai Co Ltd Beijing Liaison Office	CN	TKL	AU	ABS Italy Srl	IT
ABS Technologias del Agua SA	ES	United Pumps Australia (UPA)	AU	ABS Nopon Thai Co Ltd	TH
ABS Wastewater Technology (Pty) Ltd	ZA	Vaughan Company Inc	US	ABS Oumoer A/S	NO
ABS Wastewater Technology Ltd	UK	Warren Pumps LLC	US	ABS PolskaSp. Z.o.o.	PL
ABS Wastewater Technology Pte Ltd	SG	Weir Pumps Ltd	UK	ABS Pompalari Ltd	TR
Allweiler AG	DE	Wernert-Pumpen GmbH	DE	ABS Pompen BV	NL
Buffalo Pumps Inc	US	Wilo AG	DE	ABS Pumpen GmbH	AT
Calpeda SpA	IT	Wilo EMU GmbH	DE	ABS Pumps (Irl) Ltd	IE
Chempump	US	Worthington SpA	IT	ABS Pumps AS	EE
Davey Products Pty Ltd	AU	Yeomans Pump Company	US	ABS Pumps Corporation	CA
DDA Srl	IT	MARINE PUMPS		ABS Pumps Inc	US
Defco	US	Allweiler AG	DE	ABS Pumps Malaysia Sdn Bhd	MY
Eagle Pump & Compressor Ltd	CA	Behrens Pumpen	DE	ABS Pumps NV/SA	BE
Ebara Corporation	JP	Bombas Itur SA	ES	ABS Shanghai Co Ltd	CN
EDUR Pumpenfabrik GmbH & Co KG	DE	Caprari SpA	IT	ABS Shanghai Co Ltd Beijing Liaison Office	CN
Emile Egger et Cie SA	CH	CW-EMD	US		
		Ebara Corporation	JP		

ABS Tecnologías del Agua SA	ES	Hayward Gordon	CA	SAWA Pumpentechnik AG	CH
ABS Wastewater Technology (Pty) Ltd	ZA	HCP Pump Manufacturer Co Ltd	TW	seepex GmbH & Co KG	DE
ABS Wastewater Technology Ltd	UK	Hermetic-Pumpen GmbH	DE	seepex UK Ltd	UK
ABS Wastewater Technology Pte Ltd	SG	Hidrostal Ltd	UK	Selwood Group Ltd	UK
Acromet (Aust) Pty Ltd	AU	Honda Kiko Co Ltd	JP	Sethco Division, Met-Pro Corporation	US
Alfons de Backer & Co	BE	Hunan XD Changsha Pump Works Co Ltd	CN	Shanghai Shenbao Industrial Pump Co Ltd	CN
Alma Pompe	IT	Hung Pump Industrial Co Ltd	TW	Shijiazhuang Pump Industry Group Co Ltd	CN
Argal Srl	IT	Hydrainer Pumps Ltd	UK	Shin Shin Machinery Co Ltd	KR
Gruppo Aturia SpA	IT	Hydromatic Pumps	US	Sigma Group AS	CZ
BBA Hranice sro	CZ	Hyosung-Ebara Co Ltd	KR	Simaco Elettromeccanica Srl	IT
Best & Crompton Engineering Ltd	IN	ITT Flygt AB	SE	Slovump-Trade Sro	SK
Biral AG	CH	ITT Residential & Commercial Water	US	T Smedegaard A/S	DK
Bombas Omega SL	ES	Jabsco GmbH, ITT Industries	DE	Speck-Pumpen	DE
Buffalo Pumps Inc	US	Jabsco UK, ITT Industries	UK	SPP Pumps Ltd	UK
Calpeda SpA	IT	Jabsco US, ITT Industries	US	SRS Crisafulli Inc	US
Caprari SpA	IT	Johnston Pump	US	Oswald Suck GmbH	DE
Casals Cardona Industries SA	ES	Jung Pumpen GmbH & Co	DE	Sulzer Pumps	CH
CAT Pumps	US	Kawamoto Pump Manufacturing Co Ltd	JP	Sumoto Srl	IT
CAT Pumps (UK) Ltd	UK	Kelair Pumps Australia Pty Ltd	AU	Sunmotor International Ltd	CA
CDS-John Blue Company	US	Kielecka Fabryka Pomp Bialogon SA	PL	Swidnicka Fabryka Pomp Sp Z.o.o.	PL
Ceetak Engineering Ltd	UK	Kishor Pumps Ltd	IN	Tangshan Pump Factory	CN
Corporacion EG SA	MX	KSB Ltd	UK	Tesla Srl	IT
Cougar Industries Ltd	UK	Kubota Corporation	JP	Thompson Pump & Manufacturing Co Inc	US
Crest Pumps Ltd	UK	Lewis Pumps	US	3S Systemtechnik AG	CH
DAB Pumps SpA	IT	Little Giant Pump Company	US	TKL	AU
Davey Products Pty Ltd	AU	Lobee Pump & Machinery Company	US	Toyo Pumps Europe	BE
Defco	US	London Pumps Ltd	UK	Tsurumi (America) Inc	US
Dragflow Srl	IT	Lowara SpA, ITT Industries	IT	Tsurumi (Europe) GmbH	DE
Düchting Pumpen Maschinenfabrik GmbH	DE	Mark Grundfos Ltda	BR	Tsurumi (Shanghai) Co Ltd	CN
Eagle Pump & Compressor Ltd	CA	Marlow Pumps, ITT Water Technology	US	Tsurumi (Singapore) Pte Ltd	SG
Ebara Corporation	JP	Megator Ltd	UK	Tsurumi Manufacturing Co Ltd	JP
Ebara España Bombas SA	ES	Melotte Pumptechnology BV	NL	Tsurumi Pump (Malaysia) SDN BHD	MY
EDUR Pumpenfabrik GmbH & Co KG	DE	Metalchem-Warszawa SA	PL	Tsurumi Pump Taiwan Co Ltd	TW
Emile Egger et Cie SA	CH	Frank Mohn AS	NO	Türbosan AS	TR
Franz Eisele und Söhne GmbH & Co KG	DE	Morris Pumps	US	Ture International Industrial Ltd	CN
Engineered Products Group Pty Ltd (EPG)	AU	MTH Pumps	US	Stuart Turner Ltd	UK
Fairbanks Morse Pump	US	FE Myers	US	Tyco - Southern Cross Plant	AU
Feluwa Pumpen GmbH	DE	Nijhuis Pompen BV	NL	Tycon Alloy Industries (Hong Kong) Co Ltd	HK
Flexachem Manufacturing Ltd	IE	Nova Magnetics Burgmann Ltd	CA	United Pumps Australia (UPA)	AU
Flowmore Private Ltd	IN	Nuovo Pignone	IT	Varisco Srl	IT
Flowserve Corporation	US	Oddesse Pumpen-und Motorenfabrik GmbH	DE	Verder Group	NL
Godwin Pumps Ltd	UK	OFT (Officine Di Trevi)	IT	Versa-Matic Pump Company	US
Godwin Pumps of America Inc	US	Ondrejovicka Strojirna sro	CZ	Vertiflo Pump Company	US
Goodwin International	UK	Paco Pumps	US	Pumpenfabrik Ernst Vogel GmbH, ITT Industries	AT
Gorman-Rupp Company	US	Pedrollo SpA	IT	Warren Rupp Inc	US
Goulds Pumps, ITT Industrial & BioPharm Group	US	Peerless Pump Company	US	Weir Pumps Ltd	UK
Goulds Pumps, ITT Water Technology	US	Pentair Inc	US	Wernert-Pumpen GmbH	DE
Grindex AB	SE	Pentair Pumps SpA	IT	Wilo AG	DE
Grover Manufacturing Corporation	US	Power Pump Factory Co Ltd	PL	Wilo EMU GmbH	DE
Grundfos (Singapore) Pte Ltd	SG	PT Ebara Indonesia	ID	Witte Pumps & Technology GmbH	DE
Grundfos GmbH	DE	Pump & Package Ltd	UK	Yaltek AS	TR
Grundfos Management A/S	DK	Pump Engineering Co Pvt Ltd	IN	Yeomans Pump Company	US
Grundfos Pompe Italia Srl	IT	Pump Engineering Ltd	UK	Zoeller Pump Company	US
Grundfos Pumpen Vertrieb GmbH	AT	Pumpex Sales	SE		
Grundfos Pumps Corporation	US	Red Jacket, ITT Water Technology	US	NON-ELECTRIC SUBMERSIBLE PUMPS	
Grundfos Pumps KK	JP	Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA	Acromet (Aust) Pty Ltd	AU
Grundfos Pumps Ltd	UK	Ritz Pumpenfabrik GmbH & Co KG	DE	Alma Pompe	IT
Grundfos Pumps Pty Ltd	AU	Robot Pumps BV	NL	BBA Hranice sro	CZ
H & E Tsurumi Pump Co Ltd	HK	Rovatti Pompe	IT	Biral AG	CH
Arthur Habermann GmbH & Co KG	DE	Ruhrpumpen GmbH	DE	Bombas Omega SL	ES
Handol Pumps Ltd	KR	Ruhrpumpen Inc	US	Calama Industries Pvt Ltd	IN
Hangzhou SRT Pump Co Ltd	CN	Rütschi Fluid AG	CH	Caprari SpA	IT
Hanning & Kahl GmbH & Co KG	DE	Saer Elettropompe	IT	CAT Pumps	US
Häny AG	CH	Sakuragawa Pump Manufacturing Co Ltd	JP	CAT Pumps (UK) Ltd	UK
		Salmson Italia	IT	Ceetak Engineering Ltd	UK

Corporacion EG SA	MX	TKL	AU	Motorarg SA	AR
DAB Pumps SpA	IT	Toyo Pumps Europe	BE	MTH Pumps	US
Davey Products Pty Ltd	AU	Türbosan AS	TR	FE Myers	US
Dickow Pumpen KG	DE	Versa-Matic Pump Company	US	National Pump Company LLC	US
Dragflow Srl	IT	Warren Rupp Inc	US	Oddesse Pumpen-und Motorenfabrik GmbH	DE
Ebara Corporation	JP	Weir Minerals Division	US	OFT (Officine Di Trevi)	IT
Ebara España Bombas SA	ES	Wilo AG	DE	Paco Pumps	US
EDUR Pumpenfabrik GmbH & Co KG	DE	Wilo EMU GmbH	DE	Pedrollo SpA	IT
Engineered Products Group Pty Ltd (EPG)	AU	Witte Pumps & Technology GmbH	DE	Peerless Pump Company	US
Fairbanks Morse Pump	US	Zoeller Pump Company	US	PEME-Gourdin SA	FR
Flowmore Private Ltd	IN	SUBMERSIBLE PUMPS FOR DEEP WELL APPLICATIONS		Pump & Package Ltd	UK
Godwin Pumps Ltd	UK	Alfons de Backer & Co	BE	Red Jacket, ITT Water Technology	US
Godwin Pumps of America Inc	US	Amrit Engineering Pvt Ltd	IN	Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA
Goodwin International	UK	Batescrew Pumps	AU	Ritz Pumpenfabrik GmbH & Co KG	DE
Gorman-Rupp Company	US	Bizzi & Tedeschi Srl	IT	Rotex SA	GR
Handol Pumps Ltd	KR	Bombas Itur SA	ES	Rovatti Pompe	IT
Hangzhou SRT Pump Co Ltd	CN	Bombas Omega SL	ES	Ruhrpumpen GmbH	DE
Hanning & Kahl GmbH & Co KG	DE	Buffalo Pumps Inc	US	Ruhrpumpen Inc	US
Häny AG	CH	Cakasa (Nigeria) Co Ltd	NG	Rütschi Fluid AG	CH
Hayward Gordon	CA	Calpeda SpA	IT	Saer Elettropompe	IT
HCP Pump Manufacturer Co Ltd	TW	Caprari SpA	IT	Sakuragawa Pump Manufacturing Co Ltd	JP
Hidrostal Ltd	UK	Chem Resist Group Ltd	UK	Salmson Italia	IT
Honda Kiko Co Ltd	JP	Cougar Industries Ltd	UK	SAWA Pumpentechnik AG	CH
Hung Pump Industrial Co Ltd	TW	Crane Pumps & Systems	US	Sharp Trendys	IN
Hydrainer Pumps Ltd	UK	DAB Pumps SpA	IT	SHURflo Pump Manufacturing Co	US
Jung Pumpen GmbH & Co	DE	Drakos-Polemis Inc	GR	Sigma Group AS	CZ
Kawamoto Pump Manufacturing Co Ltd	JP	Ebara Corporation	JP	SPP Pumps Ltd	UK
Kelair Pumps Australia Pty Ltd	AU	EDUR Pumpenfabrik GmbH & Co KG	DE	Subteck Srl	IT
Kielecka Fabryka Pomp Bialogon SA	PL	Engineered Products Group Pty Ltd (EPG)	AU	Oswald Suck GmbH	DE
Kishor Pumps Ltd	IN	Flowmore Private Ltd	IN	Sulzer Pumps	CH
KSB Ltd	UK	Flowserve Corporation	US	Sumoto Srl	IT
Kubota Corporation	JP	Gorman-Rupp Company	US	Sunmotor International Ltd	CA
Little Giant Pump Company	US	Goulds Pumps, ITT Industrial & BioPharm Group	US	Taiko Kikai Industries Co Ltd	JP
Melotte Pumptechnology BV	NL	Goulds Pumps, ITT Water Technology	US	Tesla Srl	IT
Metalchem-Warszawa SA	PL	Grundfos (Singapore) Pte Ltd	SG	TKL	AU
Mody Pumps™ Inc	US	Grundfos GmbH	DE	Tyco - Southern Cross Plant	AU
Morris Pumps	US	Grundfos Management A/S	DK	Tycon Alloy Industries (Hong Kong) Co Ltd	HK
FE Myers	US	Grundfos Pompe Italia Srl	IT	Pumpenfabrik Ernst Vogel GmbH, ITT Industries	AT
OFT (Officine Di Trevi)	IT	Grundfos Pumpen Vertrieb GmbH	AT	Wafapomp SA	PL
Ondrejovicka Strojirna sro	CZ	Grundfos Pumps Corporation	US	Pumpenfabrik Wangen GmbH	DE
Paco Pumps	US	Grundfos Pumps KK	JP	Waterman Industries Ltd	IN
Peerless Pump Company	US	Grundfos Pumps Ltd	UK	Weir Pumps Ltd	UK
Power Pump Factory Co Ltd	PL	Grundfos Pumps Pty Ltd	AU	Wilo AG	DE
Pump & Package Ltd	UK	Hamworthy Svanehøj A/S	DK	Wilo EMU GmbH	DE
Pump Engineering Co Pvt Ltd	IN	Handol Pumps Ltd	KR	Worthington SpA	IT
Pumpex Sales	SE	Hangzhou SRT Pump Co Ltd	CN	WPIL Ltd	IN
Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA	Hayward Tyler® Group	UK	Yaltek AS	TR
Ritz Pumpenfabrik GmbH & Co KG	DE	Hidrostal Ltd	UK	PORTABLE SELF-PRIMING PUMPS	
Robot Pumps BV	NL	Honda Kiko Co Ltd	JP	Albany Engineering Company Ltd	UK
Rotex SA	GR	Hung Pump Industrial Co Ltd	TW	Apollo Gössnitz GmbH	DE
Rovatti Pompe	IT	Hydrainer Pumps Ltd	UK	Aurora Pump	US
Ruhrpumpen GmbH	DE	Hydromatic Pumps	US	Buffalo Pumps Inc	US
Ruhrpumpen Inc	US	ITT Flygt AB	SE	Calama Industries Pvt Ltd	IN
Saer Elettropompe	IT	ITT Residential & Commercial Water	US	Calpeda SpA	IT
Sakuragawa Pump Manufacturing Co Ltd	JP	Johnston Pump	US	Caprari SpA	IT
SAWA Pumpentechnik AG	CH	Kelair Pumps Australia Pty Ltd	AU	Cougar Industries Ltd	UK
Sethco Division, Met-Pro Corporation	US	Kishor Pumps Ltd	IN	Defco	US
Shanghai Shenbao Industrial Pump Co Ltd	CN	KSB Ltd	UK	Ebara Corporation	JP
Shijiazhuang Pump Industry Group Co Ltd	CN	Laxmi Hydraulics Pvt Ltd	IN	EBS-Ray Pumps Pty Ltd	AU
Sigma Group AS	CZ	Lowara SpA, ITT Industries	IT	EDUR Pumpenfabrik GmbH & Co KG	DE
SRS Crisafulli Inc	US	Mark Grundfos Ltda	BR	Franz Eisele und Söhne GmbH & Co KG	DE
Oswald Suck GmbH	DE	Megator Ltd	UK	Engineered Products Group Pty Ltd (EPG)	AU
Tangshan Pump Factory	CN	Monarch Industries Ltd	CA	Finder Pompe SpA	IT
Termomeccanica Pompe SpA	IT			Finish Thompson Inc	US
Thompson Pump & Manufacturing Co Inc	US				

Flowmore Private Ltd	IN
Flowserve Corporation	US
Gilbert Gilkes & Gordon Ltd	UK
Gorman-Rupp Company	US
Goulds Pumps, ITT Water Technology	US
Handol Pumps Ltd	KR
Hayward Tyler® Group	UK
Hidrotecar SA	ES
Honda Kiko Co Ltd	JP
Hunan XD Changsha Pump Works Co Ltd	CN
Iwaki America	US
Johnson Pump (India), ATE Enterprises Ltd	IN
Johnson Pump AB	SE
Johnson Pump BV	NL
Johnson Pumps of America Inc	US
Kelair Pumps Australia Pty Ltd	AU
Kestner Engineering Co Ltd	UK
Oy Kolmeks AB	FI
Kubota Corporation	JP
Lowara SpA, ITT Industries	IT
Marlow Pumps, ITT Water Technology	US
Mefiag Division, Met-Pro Corporation	US
Moyno Inc	US
MP Pumps Inc	US
MTH Pumps	US
Paco Pumps	US
Peerless Pump Company	US
Pomac Industries Group	NL
Primax Pumps	AE
Process Pumps (India) Pvt Ltd	IN
Pump & Package Ltd	UK
Raj Pumps	IN
Red Jacket, ITT Water Technology	US
Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA
Ritz Pumpenfabrik GmbH & Co KG	DE
Ruhrpumpen GmbH	DE
Ruhrpumpen Inc	US
SAWA Pumpentechnik AG	CH
Schmalenberger GmbH & Co	DE
Selwood Group Ltd	UK
Sero PumpSystems GmbH	DE
Sethco Division, Met-Pro Corporation	US
Sharp Trendys	IN
Sigma Group AS	CZ
Slovpump-Trade Sro	SK
Michael Smith Engineers Ltd	UK
SPP Pumps Ltd	UK
Standard Pump Inc	US
Sterling Fluid Systems (Americas) Inc	US
Sterling Fluid Systems (Austria)	AT
Sterling Fluid Systems (Belgium) NV	BE
Sterling Fluid Systems (France) SAS	FR
Sterling Fluid Systems (Italy) SpA	IT
Sterling Fluid Systems (Netherlands)	NL
Sterling Fluid Systems (Schweiz) AG	CH
Sterling Fluid Systems (UK) Ltd	UK
Sterling SIHI GmbH	DE
TKL	AU
Ture International Industrial Ltd	CN
Varisco Srl	IT
Verder Group	NL
Pompe Vergani	IT
Victor Pumpen GmbH	DE
Weir Specialty Pumps	US
Yaltek AS	TR

HORIZONTAL TWO-STAGE AXIALLY-SPLIT CENTRIFUGAL PUMPS (including ISO 13709, API 610 designs)

Dalian Danai Pumps Ltd	CN
Ebara Corporation	JP
EDUR Pumpenfabrik GmbH & Co KG	DE
Engineered Products Group Pty Ltd (EPG)	AU
Flowmore Private Ltd	IN
Flowserve Corporation	US
Goulds Pumps, ITT Industrial & BioPharm Group	US
Grundfos (Singapore) Pte Ltd	SG
Grundfos GmbH	DE
Grundfos Management A/S	DK
Grundfos Pompe Italia Srl	IT
Grundfos Pumpen Vertrieb GmbH	AT
Grundfos Pumps Corporation	US
Grundfos Pumps KK	JP
Grundfos Pumps Ltd	UK
Grundfos Pumps Pty Ltd	AU
Handol Pumps Ltd	KR
Hermetic-Pumpen GmbH	DE
Honda Kiko Co Ltd	JP
Kelair Pumps Australia Pty Ltd	AU
Mark Grundfos Ltda	BR
Paco Pumps	US
Peerless Pump Company	US
Pump & Package Ltd	UK
Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA
Ruhrpumpen GmbH	DE
Ruhrpumpen Inc	US
Shanghai Liansheng Pump Manufacture Co Ltd	CN
Sigma Group AS	CZ
Sulzer Pumps	CH
TKL	AU
Ture International Industrial Ltd	CN
Weir Pumps Ltd	UK

HORIZONTAL TWO-STAGE RADIALLY-SPLIT CENTRIFUGAL PUMPS (including ISO 13709, API 610 designs)

Cougar Industries Ltd	UK
Dalian Danai Pumps Ltd	CN
Ebara Corporation	JP
EDUR Pumpenfabrik GmbH & Co KG	DE
Engineered Products Group Pty Ltd (EPG)	AU
Flowmore Private Ltd	IN
Flowserve Corporation	US
Goulds Pumps, ITT Industrial & BioPharm Group	US
Handol Pumps Ltd	KR
Honda Kiko Co Ltd	JP
Kelair Pumps Australia Pty Ltd	AU
KSB Ltd	UK
Paco Pumps	US
Peerless Pump Company	US
Pulsafeeder	US
Pump & Package Ltd	UK
Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA
Ruhrpumpen GmbH	DE
Ruhrpumpen Inc	US
Shanghai Liansheng Pump Manufacture Co Ltd	CN
Sigma Group AS	CZ
Sterling Fluid Systems (Americas) Inc	US
Sterling Fluid Systems (Austria)	AT
Sterling Fluid Systems (Belgium) NV	BE

Sterling Fluid Systems (France) SAS	FR
Sterling Fluid Systems (Italy) SpA	IT
Sterling Fluid Systems (Netherlands)	NL
Sterling Fluid Systems (Schweiz) AG	CH
Sterling Fluid Systems (UK) Ltd	UK
Sterling SIHI GmbH	DE
Sulzer Pumps	CH
TKL	AU
Ture International Industrial Ltd	CN
Weir Pumps Ltd	UK

MULTI-STAGE SEGMENTAL CENTRIFUGAL PUMPS (dH > 300 m)

Cougar Industries Ltd	UK
Dickow Pumpen KG	DE
Ebara Corporation	JP
EDUR Pumpenfabrik GmbH & Co KG	DE
Engineered Products Group Pty Ltd (EPG)	AU
Ensival-Moret	BE
Flowserve Corporation	US
Goulds Pumps, ITT Industrial & BioPharm Group	US
Grundfos (Singapore) Pte Ltd	SG
Grundfos GmbH	DE
Grundfos Management A/S	DK
Grundfos Pompe Italia Srl	IT
Grundfos Pumpen Vertrieb GmbH	AT
Grundfos Pumps Corporation	US
Grundfos Pumps KK	JP
Grundfos Pumps Ltd	UK
Grundfos Pumps Pty Ltd	AU
Handol Pumps Ltd	KR
Hidráulicas HMT SA	ES
ITT Flygt AB	SE
Kelair Pumps Australia Pty Ltd	AU
Klaus Union GmbH & Co KG	DE
KSB Ltd	UK
Laxmi Hydraulics Pvt Ltd	IN
Layne/Verti-Line	US
Lowara SpA, ITT Industries	IT
Mark Grundfos Ltda	BR
Mather & Platt Pumps Ltd	IN
Paco Pumps	US
Peerless Pump Company	US
Pulsafeeder	US
Pump & Package Ltd	UK
Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA
Ruhrpumpen GmbH	DE
Ruhrpumpen Inc	US
Saer Elektropompe	IT
Shanghai Liansheng Pump Manufacture Co Ltd	CN
Sigma Group AS	CZ
Sterling Fluid Systems (Americas) Inc	US
Sterling Fluid Systems (Austria)	AT
Sterling Fluid Systems (Belgium) NV	BE
Sterling Fluid Systems (France) SAS	FR
Sterling Fluid Systems (Italy) SpA	IT
Sterling Fluid Systems (Netherlands)	NL
Sterling Fluid Systems (Schweiz) AG	CH
Sterling Fluid Systems (UK) Ltd	UK
Sterling SIHI GmbH	DE
Sulzer Pumps	CH
TKL	AU
Torishima Pump Mfg Co Ltd	JP
United Pumps Australia (UPA)	AU

Pumpenfabrik Ernst Vogel GmbH, AT
ITT Industries
Wafapomp SA PL

**HORIZONTAL MULTI-STAGE
AXIALLY-SPLIT CENTRIFUGAL PUMPS
(including ISO 13709, API 610 designs)**

A-Ryung Machinery Ind Co Ltd KR
Cougar Industries Ltd UK
Dalian Danai Pumps Ltd CN
Defco US
Düchting Pumpen Maschinerfabrik GmbH DE
Ebara Corporation JP
EDUR Pumpenfabrik GmbH & Co KG DE
Engineered Products Group Pty Ltd (EPG) AU
Ensival-Moret BE
Flowmore Private Ltd IN
Flowserve Corporation US
Goulds Pumps, US
ITT Industrial & BioPharm Group
Handol Pumps Ltd KR
Hermetic-Pumpen GmbH DE
Hidráulicas HMT SA ES
Hilge Pumps Ltd UK
Honda Kiko Co Ltd JP
Kelair Pumps Australia Pty Ltd AU
Kubota Corporation JP
Layne/Verti-Line US
MTH Pumps US
Nuovo Pignone IT
Paco Pumps US
Peerless Pump Company US
Pulsafeeder US
Pump & Package Ltd UK
Rhine Ruhr Pumps & Valves (Pty) Ltd ZA
Ruhrpumpen GmbH DE
Ruhrpumpen Inc US
Shanghai Liansheng CN
Pump Manufacture Co Ltd
Sigma Group AS CZ
Sulzer Pumps CH
TKL AU
Ture International Industrial Ltd CN
United Pumps Australia (UPA) AU
Wafapomp SA PL
Weir Pumps Ltd UK

**HORIZONTAL MULTI-STAGE
RADIALLY-SPLIT CENTRIFUGAL PUMPS
(including ISO 13709, API 610 designs)**

ACD Inc US
Aker Kvaerner Eureka Pump Systems NO
Apollo Gössnitz GmbH DE
A-Ryung Machinery Ind Co Ltd KR
Dalian Danai Pumps Ltd CN
Ebara Corporation JP
EDUR Pumpenfabrik GmbH & Co KG DE
Engineered Products Group Pty Ltd (EPG) AU
Ensival-Moret BE
Fairbanks Morse Pump US
Flowmore Private Ltd IN
Flowserve Corporation US
Goulds Pumps, US
ITT Industrial & BioPharm Group
Handol Pumps Ltd KR
Hilge Pumps Ltd UK
Honda Kiko Co Ltd JP
Johnston Pump US
Kelair Pumps Australia Pty Ltd AU

Klaus Union GmbH & Co KG DE
KSB Ltd UK
Kubota Corporation JP
Lutz (UK) Ltd UK
Mather & Platt Pumps Ltd IN
Megator Ltd UK
Nasosenergomash UA
National Pump Company LLC US
Nikkiso Co Ltd JP
Nuovo Pignone IT
Paco Pumps US
Peerless Pump Company US
Pump & Package Ltd UK
Rhine Ruhr Pumps & Valves (Pty) Ltd ZA
Ruhrpumpen GmbH DE
Ruhrpumpen Inc US
Shanghai Liansheng CN
Pump Manufacture Co Ltd
Sigma Group AS CZ
Sterling Fluid Systems (Americas) Inc US
Sterling Fluid Systems (Austria) AT
Sterling Fluid Systems (Belgium) NV BE
Sterling Fluid Systems (France) SAS FR
Sterling Fluid Systems (Italy) SpA IT
Sterling Fluid Systems (Netherlands) NL
Sterling Fluid Systems (Schweiz) AG CH
Sterling Fluid Systems (UK) Ltd UK
Sterling SIHI GmbH DE
Sulzer Pumps CH
TKL AU
Torishima Pump Mfg Co Ltd JP
Ture International Industrial Ltd CN
United Pumps Australia (UPA) AU
Weir Gabbioneta Srl IT
Weir Pumps Ltd UK

**LARGE VERTICAL MULTI-STAGE
CENTRIFUGAL PUMPS
(including ISO 13709, API 610 designs)**

Dalian Danai Pumps Ltd CN
Defco US
Düchting Pumpen Maschinerfabrik GmbH DE
Ebara Corporation JP
EDUR Pumpenfabrik GmbH & Co KG DE
Flowmore Private Ltd IN
Hidráulicas HMT SA ES
Iwaki Co Ltd JP
Iwaki Europe GmbH DE
Klaus Union GmbH & Co KG DE
Layne/Verti-Line US
MTH Pumps US
Nasosenergomash UA
Nuovo Pignone IT
Pulsafeeder US
Rhine Ruhr Pumps & Valves (Pty) Ltd ZA
United Pumps Australia (UPA) AU
Wafapomp SA PL

**SINGLE-STAGE CENTRIFUGAL PUMPS
WITH INTEGRAL GEARING**

Cakasa (Nigeria) Co Ltd NG
Caprari SpA IT
CDR Pompe SpA IT
CDS-John Blue Company US
Concentric Pumps Ltd UK
Cougar Industries Ltd UK
DAB Pumps SpA IT

Debem IT
Defco US
Ebara Corporation JP
EDUR Pumpenfabrik GmbH & Co KG DE
Engineered Products Group Pty Ltd (EPG) AU
Ensival-Moret BE
Environamics Corporation US
Finder Pompe SpA IT
Flojet Corporation US
Flowmore Private Ltd IN
Fristam Pumps (UK) Ltd UK
Fristam Pumps USA US
Fristram Pumpen DE
GIW Industries Inc US
Hale Products Europe Ltd UK
Handol Pumps Ltd KR
Hidráulicas HMT SA ES
Honda Kiko Co Ltd JP
Ilsung Precision Industry Company KR
Inoxpa SA ES
Iwaki America US
Jiangsu Haishi Pump Co Ltd CN
Kelair Pumps Australia Pty Ltd AU
Klaus Union GmbH & Co KG DE
London Pumps Ltd UK
Lutz (UK) Ltd UK
Micropump Ltd UK
Nasosenergomash UA
Nikkiso Co Ltd JP
Nuovo Pignone IT
Pacer Pumps US
Paco Pumps US
Peerless Pump Company US
Pump & Package Ltd UK
Rhine Ruhr Pumps & Valves (Pty) Ltd ZA
Ruhrpumpen GmbH DE
Ruhrpumpen Inc US
Sacem SpA IT
Sigma Group AS CZ
Siwatec AS CZ
Slovump-Trade Sro SK
Tianjin Pumps & Machinery Group Co Ltd CN
TKL AU
TriVista Engineering Ltd UK
Ture International Industrial Ltd CN
Tycon Alloy Industries (Hong Kong) Co Ltd HK
United Pumps Australia (UPA) AU

**MULTI-STAGE CENTRIFUGAL PUMPS
WITH INTEGRAL GEARING**

Apollo Gössnitz GmbH DE
Best & Crompton Engineering Ltd IN
Calama Industries Pvt Ltd IN
Caprari SpA IT
DAB Pumps SpA IT
Düchting Pumpen Maschinerfabrik GmbH DE
Ebara Corporation JP
EDUR Pumpenfabrik GmbH & Co KG DE
Engineered Products Group Pty Ltd (EPG) AU
Flowmore Private Ltd IN
Fristam Pumps (UK) Ltd UK
Fristam Pumps USA US
Fristram Pumpen DE
Handol Pumps Ltd KR
Hidráulicas HMT SA ES
Honda Kiko Co Ltd JP

Kelair Pumps Australia Pty Ltd	AU	Sterling Fluid Systems (Italy) SpA	IT	Kinder-Janes Engineers Ltd	UK
KNF Neuberger GmbH	DE	Sterling Fluid Systems (Netherlands)	NL	KNF Neuberger GmbH	DE
Layne/Verti-Line	US	Sterling Fluid Systems (Schweiz) AG	CH	KSB Ltd	UK
Leszno Pump Factory	PL	Sterling Fluid Systems (UK) Ltd	UK	Lewis Pumps	US
Odessa Pumpen-und Motorenfabrik GmbH	DE	Sterling SIHI GmbH	DE	Linatex Ltd	UK
Paco Pumps	US	Sulzer Pumps	CH	Little Giant Pump Company	US
Peerless Pump Company	US	Swidnicka Fabryka Pomp Sp Z.o.o.	PL	Lowara SpA, ITT Industries	IT
Pump & Package Ltd	UK	TKL	AU	Mark Grundfos Ltda	BR
Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA	Toyo Pumps Europe	BE	Marlow Pumps, ITT Water Technology	US
Ritz Pumpenfabrik GmbH & Co KG	DE	United Pumps Australia (UPA)	AU	Metso Minerals (Sala) AB	SE
Ruhrpumpen GmbH	DE	Wafapomp SA	PL	Monarch Industries Ltd	CA
Ruhrpumpen Inc	US			Nova Magnetics Burghmann Ltd	CA
Sigma Group AS	CZ	CENTRIFUGAL PUMPS FOR		Omel Ltda	BR
T Smedegaard A/S	DK	HANDLING SOLIDS < 10 MM		Paco Pumps	US
TKL	AU	Abel GmbH & Co KG	DE	Peerless Pump Company	US
TriVista Engineering Ltd	UK	Acromet (Aust) Pty Ltd	AU	Plenty Mirreles Pumps	UK
Ture International Industrial Ltd	CN	Allweiler AG	DE	Pump & Package Ltd	UK
Tycon Alloy Industries (Hong Kong) Co Ltd	HK	Argal Srl	IT	Pump Engineering Ltd	UK
United Pumps Australia (UPA)	AU	Asco Pompe srl	IT	Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA
Wilo AG	DE	Best & Crompton Engineering Ltd	IN	Robot Pumps BV	NL
Wilo EMU GmbH	DE	Caprari SpA	IT	Ruhrpumpen GmbH	DE
		Chem Resist Group Ltd	UK	Ruhrpumpen Inc	US
CENTRIFUGAL PUMPS FOR PULP		Chicago Pump Company	US	Savino Barbera	IT
Allweiler AG	DE	Cornell	US	Scheerle AG	CH
Apollo Gössnitz GmbH	DE	Dalian Danai Pumps Ltd	CN	Schmalenberger GmbH & Co	DE
Asco Pompe srl	IT	Discflo Corporation	US	Selwood Group Ltd	UK
Camaction Avonpump Ltd	UK	Düchtling Pumpen Maschinerfabrik GmbH	DE	Shijiazhuang Pump Industry Group Co Ltd	CN
Cornell	US	Ebara Corporation	JP	Sigma Group AS	CZ
Corporacion EG SA	MX	EDUR Pumpenfabrik GmbH & Co KG	DE	SPP Pumps Ltd	UK
Desmi GmbH	DE	Franz Eisele und Söhne GmbH & Co KG	DE	Sterling Fluid Systems (Americas) Inc	US
Ebara Corporation	JP	Engineered Products Group Pty Ltd (EPG)	AU	Sterling Fluid Systems (Austria)	AT
EBS-Ray Pumps Pty Ltd	AU	ESSCO Pumps & Controls	US	Sterling Fluid Systems (Belgium) NV	BE
EDUR Pumpenfabrik GmbH & Co KG	DE	Fapmo	FR	Sterling Fluid Systems (France) SAS	FR
Engineered Products Group Pty Ltd (EPG)	AU	Feluwa Pumpen GmbH	DE	Sterling Fluid Systems (Italy) SpA	IT
Finder Pompe SpA	IT	Flexachem Manufacturing Ltd	IE	Sterling Fluid Systems (Netherlands)	NL
Finish Thompson Inc	US	Flowmore Private Ltd	IN	Sterling Fluid Systems (Schweiz) AG	CH
Flowmore Private Ltd	IN	Flowserve Corporation	US	Sterling Fluid Systems (UK) Ltd	UK
Flowserve Corporation	US	Flux Pumps Corporation	US	Sterling SIHI GmbH	DE
Gorman-Rupp Company	US	GIW Industries Inc	US	Sulzer Pumps	CH
Goulds Pumps,	US	GMP SpA	IT	Tangshan Pump Factory	CN
ITT Industrial & BioPharm Group		Godwin Pumps Ltd	UK	Terex Powertrain Ltd	UK
GPM Pumps Inc	US	Goodwin International	UK	Titanium Tantalum Products Ltd	IN
Arthur Habermann GmbH & Co KG	DE	Gorman-Rupp Company	US	TKL	AU
Handol Pumps Ltd	KR	Goulds Pumps,	US	Toyo Pumps Europe	BE
Hayward Tyler® Group	UK	ITT Industrial & BioPharm Group		Tuthill Corporation	US
Hidrostal Ltd	UK	Goulds Pumps, ITT Water Technology	US	Varisco Srl	IT
Hidrotecar SA	ES	GPM Pumps Inc	US	Verder Group	NL
Honda Kiko Co Ltd	JP	Grundfos (Singapore) Pte Ltd	SG	Vertiflo Pump Company	US
Iwaki America	US	Grundfos GmbH	DE	Victor Pumpen GmbH	DE
Kelair Pumps Australia Pty Ltd	AU	Grundfos Management A/S	DK	Willy Vogel AG	DE
Metso Minerals (Sala) AB	SE	Grundfos Pompe Italia Srl	IT	Pumpenfabrik Ernst Vogel GmbH,	AT
Nasosenergomash	UA	Grundfos Pumpen Vertrieb GmbH	AT	ITT Industries	
Omel Ltda	BR	Grundfos Pumps Corporation	US	Pumpenfabrik Wangen GmbH	DE
Paco Pumps	US	Grundfos Pumps KK	JP	CH Warman Pump Group	ZA
Peerless Pump Company	US	Grundfos Pumps Ltd	UK	Weir Minerals Division	US
Process Pumps (India) Pvt Ltd	IN	Grundfos Pumps Pty Ltd	AU	Weir Pumps Ltd	UK
Pump & Package Ltd	UK	Handol Pumps Ltd	KR	A R Wilfley & Sons Inc	US
Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA	Hayward Gordon	CA	Yeomans Pump Company	US
Ruhrpumpen GmbH	DE	Hermetic-Pumpen GmbH	DE		
Ruhrpumpen Inc	US	Hidrostal Ltd	UK	CENTRIFUGAL PUMPS FOR	
Scheerle AG	CH	Hilge Pumps Ltd	UK	HANDLING SOLIDS > 10 MM	
Sigma Group AS	CZ	Homa Pumpenfabrik GmbH	DE	Abel GmbH & Co KG	DE
Sterling Fluid Systems (Americas) Inc	US	Honda Kiko Co Ltd	JP	Acromet (Aust) Pty Ltd	AU
Sterling Fluid Systems (Austria)	AT	ITT Flygt AB	SE	Argal Srl	IT
Sterling Fluid Systems (Belgium) NV	BE	Kelair Pumps Australia Pty Ltd	AU	Asco Pompe srl	IT
Sterling Fluid Systems (France) SAS	FR	Kestner Engineering Co Ltd	UK	Best & Crompton Engineering Ltd	IN

Caprari SpA	IT	Schmalenberger GmbH & Co	DE	Ebara Corporation	JP
Casals Cardona Industries SA	ES	Selwood Group Ltd	UK	EDUR Pumpenfabrik GmbH & Co KG	DE
Chem Resist Group Ltd	UK	Shijiazhuang Pump Industry Group Co Ltd	CN	Engineered Products Group Pty Ltd (EPG)	AU
Chicago Pump Company	US	Sigma Group AS	CZ	Feluwa Pumpen GmbH	DE
Discflo Corporation	US	SPP Pumps Ltd	UK	Flowserve Corporation	US
Dragflow Srl	IT	Sterling Fluid Systems (Americas) Inc	US	Gorman-Rupp Company	US
Düchting Pumpen Maschinenfabrik GmbH	DE	Sterling Fluid Systems (Austria)	AT	Goulds Pumps, ITT Industrial & BioPharm Group	US
Ebara Corporation	JP	Sterling Fluid Systems (Belgium) NV	BE	Handol Pumps Ltd	KR
EBS-Ray Pumps Pty Ltd	AU	Sterling Fluid Systems (France) SAS	FR	Hayward Gordon	CA
EDUR Pumpenfabrik GmbH & Co KG	DE	Sterling Fluid Systems (Italy) SpA	IT	Hidrostal Ltd	UK
Franz Eisele und Söhne GmbH & Co KG	DE	Sterling Fluid Systems (Netherlands)	NL	Honda Kiko Co Ltd	JP
Engineered Products Group Pty Ltd (EPG)	AU	Sterling Fluid Systems (Schweiz) AG	CH	ITT Flygt AB	SE
ESSCO Pumps & Controls	US	Sterling Fluid Systems (UK) Ltd	UK	Kelair Pumps Australia Pty Ltd	AU
Fapmo	FR	Sterling SIHI GmbH	DE	KSB Ltd	UK
Feluwa Pumpen GmbH	DE	Tangshan Pump Factory	CN	Little Giant Pump Company	US
Flexachem Manufacturing Ltd	IE	Terex Powertrain Ltd	UK	Marlow Pumps, ITT Water Technology	US
Flowmore Private Ltd	IN	Titanium Tantalum Products Ltd	IN	Metso Minerals (Sala) AB	SE
Flowserve Corporation	US	TKL	AU	Mody Pumps™ Inc	US
Flux Pumps Corporation	US	Toyo Pumps Europe	BE	Moyno Inc	US
GIW Industries Inc	US	Tuthill Corporation	US	Paco Pumps	US
GMP SpA	IT	Varisco Srl	IT	Peerless Pump Company	US
Godwin Pumps Ltd	UK	Vaughan Company Inc	US	Pump & Package Ltd	UK
Goodwin International	UK	Vertiflo Pump Company	US	Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA
Gorman-Rupp Company	US	Victor Pumpen GmbH	DE	Robot Pumps BV	NL
Goulds Pumps, ITT Industrial & BioPharm Group	US	Willy Vogel AG	DE	Rotex SA	GR
Goulds Pumps, ITT Water Technology	US	Pumpenfabrik Ernst Vogel GmbH, ITT Industries	AT	Ruhrpumpen GmbH	DE
GPM Pumps Inc	US	Pumpenfabrik Wangen GmbH	DE	Ruhrpumpen Inc	US
Grundfos (Singapore) Pte Ltd	SG	CH Warman Pump Group	ZA	Scheerle AG	CH
Grundfos GmbH	DE	Weir Minerals Division	US	Selwood Group Ltd	UK
Grundfos Management A/S	DK	A R Wilfley & Sons Inc	US	Shijiazhuang Pump Industry Group Co Ltd	CN
Grundfos Pompe Italia Srl	IT	Yeomans Pump Company	US	Sigma Group AS	CZ
Grundfos Pumpen Vertrieb GmbH	AT	NON-CLOGGING PUMPS		Sterling Fluid Systems (Americas) Inc	US
Grundfos Pumps Corporation	US	Abel GmbH & Co KG	DE	Sterling Fluid Systems (Austria)	AT
Grundfos Pumps KK	JP	ABS Deutschland GmbH	DE	Sterling Fluid Systems (Belgium) NV	BE
Grundfos Pumps Ltd	UK	ABS Finland Oy	FI	Sterling Fluid Systems (France) SAS	FR
Grundfos Pumps Pty Ltd	AU	ABS France SAS	FR	Sterling Fluid Systems (Italy) SpA	IT
Handol Pumps Ltd	KR	ABS Group	SE	Sterling Fluid Systems (Netherlands)	NL
Hayward Gordon	CA	ABS Hellas SA	GR	Sterling Fluid Systems (Schweiz) AG	CH
Hidrostal Ltd	UK	ABS Hidrobomba SA	PL	Sterling Fluid Systems (UK) Ltd	UK
Homa Pumpenfabrik GmbH	DE	ABS Hungary Trading	HU	Sterling SIHI GmbH	DE
Honda Kiko Co Ltd	JP	ABS Industria de Bombas Centrifugas Ltda	BR	Sulzer Pumps	CH
ITT Flygt AB	SE	ABS International Srl	IT	Terex Powertrain Ltd	UK
Kelair Pumps Australia Pty Ltd	AU	ABS Italy Srl	IT	TKL	AU
Kestner Engineering Co Ltd	UK	ABS Nopon Thai Co Ltd	TH	Varisco Srl	IT
Kinder-Janes Engineers Ltd	UK	ABS Oumoer A/S	NO	Vaughan Company Inc	US
KNF Neuberger GmbH	DE	ABS PolskaSp. Z.o.o.	PL	Verder Group	NL
KSB Ltd	UK	ABS Pompalari Ltd	TR	Pumpenfabrik Ernst Vogel GmbH, ITT Industries	AT
Lewis Pumps	US	ABS Pompen BV	NL	CH Warman Pump Group	ZA
Little Giant Pump Company	US	ABS Pumpen GmbH	AT	Warren Rupp Inc	US
Lowara SpA, ITT Industries	IT	ABS Pumps (Irl) Ltd	IE	Yeomans Pump Company	US
Mark Grundfos Ltda	BR	ABS Pumps AS	EE	SUBMERSIBLE NON-CLOGGING PUMPS	
Marlow Pumps, ITT Water Technology	US	ABS Pumps Corporation	CA	Abel GmbH & Co KG	DE
Metso Minerals (Sala) AB	SE	ABS Pumps Inc	US	ABS Deutschland GmbH	DE
Omel Ltda	BR	ABS Pumps Malaysia Sdn Bhd	MY	ABS Finland Oy	FI
Ondrejovicka Strojirna sro	CZ	ABS Pumps NV/SA	BE	ABS France SAS	FR
Paco Pumps	US	ABS Shanghai Co Ltd	CN	ABS Group	SE
Peerless Pump Company	US	ABS Shanghai Co Ltd Beijing Liaison Office	CN	ABS Hellas SA	GR
Pump & Package Ltd	UK	ABS Technologias del Agua SA	ES	ABS Hidrobomba SA	PL
Pump Engineering Ltd	UK	ABS Wastewater Technology (Pty) Ltd	ZA	ABS Hungary Trading	HU
Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA	ABS Wastewater Technology Ltd	UK	ABS Industria de Bombas Centrifugas Ltda	BR
Robot Pumps BV	NL	ABS Wastewater Technology Pte Ltd	SG	ABS International Srl	IT
Ruhrpumpen GmbH	DE	Bombas Itur SA	ES	ABS Italy Srl	IT
Ruhrpumpen Inc	US	Caprari SpA	IT	ABS Nopon Thai Co Ltd	TH
Scheerle AG	CH	Desmi GmbH	DE		

ABS Oumoer A/S	NO	Hydrainer Pumps Ltd	UK	Tsurumi (Europe) GmbH	DE
ABS Polska Sp. Z.o.o.	PL	Hydromatic Pumps	US	Tsurumi (Shanghai) Co Ltd	CN
ABS Pompalari Ltd	TR	Hyosung-Ebara Co Ltd	KR	Tsurumi (Singapore) Pte Ltd	SG
ABS Pompen BV	NL	ITT Flygt AB	SE	Tsurumi Manufacturing Co Ltd	JP
ABS Pumpen GmbH	AT	Johnson Pump (India), ATE Enterprises Ltd	IN	Tsurumi Pump (Malaysia) SDN BHD	MY
ABS Pumps (Irl) Ltd	IE	Johnson Pump AB	SE	Tsurumi Pump Taiwan Co Ltd	TW
ABS Pumps AS	EE	Johnson Pump BV	NL	Türbosan AS	TR
ABS Pumps Corporation	CA	Johnson Pumps of America Inc	US	United Pumps Australia (UPA)	AU
ABS Pumps Inc	US	Jung Pumpen GmbH & Co	DE	Vaughan Company Inc	US
ABS Pumps Malaysia Sdn Bhd	MY	Kawamoto Pump Manufacturing Co Ltd	JP	Verder Group	NL
ABS Pumps NV/SA	BE	Kelair Pumps Australia Pty Ltd	AU	Vertiflo Pump Company	US
ABS Shanghai Co Ltd	CN	Kinder-Janes Engineers Ltd	UK	Wafapomp SA	PL
ABS Shanghai Co Ltd Beijing Liaison Office	CN	Kishor Pumps Ltd	IN	Pumpenfabrik Wangen GmbH	DE
ABS Tecnologias del Agua SA	ES	KSB Ltd	UK	CH Warman Pump Group	ZA
ABS Wastewater Technology (Pty) Ltd	ZA	Kubota Corporation	JP	Warren Rupp Inc	US
ABS Wastewater Technology Ltd	UK	Little Giant Pump Company	US	Weir Minerals Division	US
ABS Wastewater Technology Pte Ltd	SG	London Pumps Ltd	UK	Weir Specialty Pumps	US
Alma Pompe	IT	March May Ltd	UK	Wernert-Pumpen GmbH	DE
Apollo Gössnitz GmbH	DE	Marlow Pumps, ITT Water Technology	US	WPIL Ltd	IN
A-Ryung Machinery Ind Co Ltd	KR	Matra SpA	IT	Yaltek AS	TR
Bombas Omega SL	ES	Megator Ltd	UK	Yeomans Pump Company	US
Caprari SpA	IT	Melotte Pumptechnology BV	NL	Zoeller Pump Company	US
Carver Pump Company	US	Metachem-Warszawa SA	PL	MIXED-FLOW PUMPS	
Casals Cardona Industries SA	ES	Mody Pumps™ Inc	US	ABS Deutschland GmbH	DE
Catag AG	CH	Monarch Industries Ltd	CA	ABS Finland Oy	FI
Chem Resist Group Ltd	UK	Morris Pumps	US	ABS France SAS	FR
Chicago Pump Company	US	FE Myers	US	ABS Group	SE
Cornell	US	Nasosenergomash	UA	ABS Hellas SA	GR
Cougar Industries Ltd	UK	Nijhuis Pompen BV	NL	ABS Hidrobomba SA	PL
Crane Pumps & Systems	US	Nuovo Pignone	IT	ABS Hungary Trading	HU
Davey Products Pty Ltd	AU	Oddesse Pumpen-und Motorenfabrik GmbH	DE	ABS Industria de Bombas Centrifugas Ltda	BR
DDA Srl	IT	OFT (Officine Di Trevi)	IT	ABS International Srl	IT
Desmi GmbH	DE	Omel Ltda	BR	ABS Italy Srl	IT
Discflo Corporation	US	Ondrejovicka Strojirna sro	CZ	ABS Nopon Thai Co Ltd	TH
Dragflow Srl	IT	Paco Pumps	US	ABS Oumoer A/S	NO
Ebara Corporation	JP	Pedrollo SpA	IT	ABS Polska Sp. Z.o.o.	PL
EDUR Pumpenfabrik GmbH & Co KG	DE	Peerless Pump Company	US	ABS Pompalari Ltd	TR
Engineered Products Group Pty Ltd (EPG)	AU	Plenty Mirreles Pumps	UK	ABS Pompen BV	NL
Ensival-Moret	BE	Pomac Industries Group	NL	ABS Pumpen GmbH	AT
ESSCO Pumps & Controls	US	PT Ebara Indonesia	ID	ABS Pumps (Irl) Ltd	IE
Feluwa Pumpen GmbH	DE	Pump & Package Ltd	UK	ABS Pumps AS	EE
Flotronic Pumps Ltd	UK	Pump Engineering Ltd	UK	ABS Pumps Corporation	CA
Gilbert Gilkes & Gordon Ltd	UK	Pumpex Sales	SE	ABS Pumps Inc	US
GMP SpA	IT	Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA	ABS Pumps Malaysia Sdn Bhd	MY
Godwin Pumps Ltd	UK	Robot Pumps BV	NL	ABS Pumps NV/SA	BE
Godwin Pumps of America Inc	US	Rotex SA	GR	ABS Shanghai Co Ltd	CN
Goodwin International	UK	Ruhrpumpen GmbH	DE	ABS Shanghai Co Ltd Beijing Liaison Office	CN
Gorman-Rupp Company	US	Ruhrpumpen Inc	US	ABS Tecnologias del Agua SA	ES
Goulds Pumps, ITT Industrial & BioPharm Group	US	Rütschi Fluid AG	CH	ABS Wastewater Technology (Pty) Ltd	ZA
Goulds Pumps, ITT Water Technology	US	Sakuragawa Pump Manufacturing Co Ltd	JP	ABS Wastewater Technology Ltd	UK
Grindex AB	SE	Selwood Group Ltd	UK	ABS Wastewater Technology Pte Ltd	SG
H & E Tsurumi Pump Co Ltd	HK	Shanghai Shenbao Industrial Pump Co Ltd	CN	Aker Kvaerner Eureka Pump Systems	NO
Arthur Habermann GmbH & Co KG	DE	Shijiazhuang Pump Industry Group Co Ltd	CN	Andritz AG	AT
Handol Pumps Ltd	KR	Shin Shin Machinery Co Ltd	KR	Batescrew Pumps	AU
Hangzhou SRT Pump Co Ltd	CN	Sigma Group AS	CZ	Cakasa (Nigeria) Co Ltd	NG
Hanning & Kahl GmbH & Co KG	DE	Simaco Elettromeccanica Srl	IT	Calama Industries Pvt Ltd	IN
Häny AG	CH	Slovpump-Trade Sro	SK	Caprari SpA	IT
Hayward Gordon	CA	Speck-Pumpen	DE	Carver Pump Company	US
HCP Pump Manufacturer Co Ltd	TW	SRS Crisafulli Inc	US	Ceetak Engineering Ltd	UK
Herborner Pumpenfabrik	DE	Oswald Suck GmbH	DE	Chung Woo Industrial Co Ltd	KR
Hidrostal Ltd	UK	Swidnicka Fabryka Pomp Sp Z.o.o.	PL	Cornell	US
Homa Pumpenfabrik GmbH	DE	Tangshan Pump Factory	CN	Corporacion EG SA	MX
Honda Kiko Co Ltd	JP	Thompson Pump & Manufacturing Co Inc	US	Dempster Industries Inc	US
Hung Pump Industrial Co Ltd	TW	TKL	AU	Drakos-Polemis Inc	GR
		Tsurumi (America) Inc	US	Ebara Corporation	JP

Ebara Fluid Handling	US	Tsurumi (Singapore) Pte Ltd	SG	H & E Tsurumi Pump Co Ltd	HK
Ebara Pumps Europe SpA	IT	Tsurumi Manufacturing Co Ltd	JP	Herborner Pumpenfabrik	DE
EDUR Pumpenfabrik GmbH & Co KG	DE	Tsurumi Pump (Malaysia) SDN BHD	MY	Hidrostal Ltd	UK
Franz Eisele und Söhne GmbH & Co KG	DE	Tsurumi Pump Taiwan Co Ltd	TW	Hidrotecar SA	ES
Engineered Products Group Pty Ltd (EPG)	AU	Türbosan AS	TR	Homa Pumpenfabrik GmbH	DE
Fapmo	FR	Ture International Industrial Ltd	CN	Iron Pump A/S	DK
Flowserve Corporation	US	Voltas Ltd	IN	ITT Flygt AB	SE
Flux-Geräte GmbH	DE	Wafapomp SA	PL	Johnson Pump (India), ATE Enterprises Ltd	IN
Goulds Pumps,	US	Waterman Industries Ltd	IN	Johnson Pump AB	SE
ITT Industrial & BioPharm Group		Weir Gabbioneta Srl	IT	Johnson Pump BV	NL
H & E Tsurumi Pump Co Ltd	HK	Weir Pumps Ltd	UK	Johnson Pumps of America Inc	US
Hangzhou SRT Pump Co Ltd	CN	WPIL Ltd	IN	Johnston Pump	US
Herborner Pumpenfabrik	DE	Yaltek AS	TR	Kelair Pumps Australia Pty Ltd	AU
Hidrotecar SA	ES			Kestner Engineering Co Ltd	UK
Hunan XD Changsha Pump Works Co Ltd	CN	AXIAL-FLOW PUMPS		Klaus Union GmbH & Co KG	DE
Hung Pump Industrial Co Ltd	TW	ABS Deutschland GmbH	DE	KSB Ltd	UK
Hyosung-Ebara Co Ltd	KR	ABS Finland Oy	FI	Kubota Corporation	JP
Iron Pump A/S	DK	ABS France SAS	FR	Layne/Verti-Line	US
ITT Flygt AB	SE	ABS Group	SE	Macquarrie Corporation	NZ
Johnston Pump	US	ABS Hellas SA	GR	Mather & Platt Pumps Ltd	IN
Kelair Pumps Australia Pty Ltd	AU	ABS Hidrobomba SA	PL	MP Pumps Inc	US
Kinder-Janes Engineers Ltd	UK	ABS Hungary Trading	HU	National Pump Company LLC	US
KSB Ltd	UK	ABS Industria de Bombas Centrifugas Ltda	BR	Paco Pumps	US
Kubota Corporation	JP	ABS International Srl	IT	Patterson Pump Company	US
Layne/Verti-Line	US	ABS Italy Srl	IT	Peerless Pump Company	US
Macquarrie Corporation	NZ	ABS Nopon Thai Co Ltd	TH	Plenty Mirreless Pumps	UK
Mather & Platt Pumps Ltd	IN	ABS Oumoer A/S	NO	Pump & Package Ltd	UK
Matra SpA	IT	ABS PolskaSp. Z.o.o.	PL	Red Jacket, ITT Water Technology	US
Micro Pump Inc	US	ABS Pompalari Ltd	TR	Reddy-Bufferaloes Pump Inc	US
National Pump Company LLC	US	ABS Pompen BV	NL	Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA
Nijhuis Pompen BV	NL	ABS Pumpen GmbH	AT	Rotex SA	GR
Oddesse Pumpen-und Motorenfabrik GmbH	DE	ABS Pumps (Iri) Ltd	IE	Rovatti Pompe	IT
Paco Pumps	US	ABS Pumps AS	EE	Ruhrpumpen GmbH	DE
Packo Inox NV	BE	ABS Pumps Corporation	CA	Ruhrpumpen Inc	US
Patterson Pump Company	US	ABS Pumps Inc	US	SAWA Pumpentechnik AG	CH
Peerless Pump Company	US	ABS Pumps Malaysia Sdn Bhd	MY	seepex GmbH & Co KG	DE
PEME-Gourdin SA	FR	ABS Pumps NV/SA	BE	seepex UK Ltd	UK
Pump & Package Ltd	UK	ABS Shanghai Co Ltd	CN	Shanxi Jishan Qinglong Pump Industry Co Ltd	CN
Reddy-Bufferaloes Pump Inc	US	ABS Shanghai Co Ltd Beijing Liaison Office	CN	Shin Shin Machinery Co Ltd	KR
Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA	ABS Tecnologias del Agua SA	ES	Sigma Group AS	CZ
Ritz Pumpenfabrik GmbH & Co KG	DE	ABS Wastewater Technology (Pty) Ltd	ZA	Siwatec AS	CZ
Rovatti Pompe	IT	ABS Wastewater Technology Ltd	UK	Smith & Loveless Inc	US
Ruhrpumpen GmbH	DE	ABS Wastewater Technology Pte Ltd	SG	Michael Smith Engineers Ltd	UK
Ruhrpumpen Inc	US	ACD Inc	US	SRS Crisafulli Inc	US
Rütschi Fluid AG	CH	Aker Kvaerner Eureka Pump Systems	NO	Sulzer Pumps	CH
Sakuragawa Pump Manufacturing Co Ltd	JP	Allweiler AG	DE	Tangshan Pump Factory	CN
SAWA Pumpentechnik AG	CH	Andritz AG	AT	TKL	AU
Seko Bono Exacta SpA	IT	Apollo Gössnitz GmbH	DE	Torishima Pump Mfg Co Ltd	JP
Seko Ltd	UK	Batescrew Pumps	AU	TriVista Engineering Ltd	UK
Shanxi Jishan Qinglong Pump Industry Co Ltd	CN	Calama Industries Pvt Ltd	IN	Tsurumi (America) Inc	US
Shijiazhuang Pump Industry Group Co Ltd	CN	Caprari SpA	IT	Tsurumi (Europe) GmbH	DE
Shin Shin Machinery Co Ltd	KR	Carver Pump Company	US	Tsurumi (Shanghai) Co Ltd	CN
Sigma Group AS	CZ	Colfax Pump Group	US	Tsurumi (Singapore) Pte Ltd	SG
Siwatec AS	CZ	Corporacion EG SA	MX	Tsurumi Manufacturing Co Ltd	JP
Slovapump-Trade Sro	SK	Dempster Industries Inc	US	Tsurumi Pump (Malaysia) SDN BHD	MY
Smith & Loveless Inc	US	Drakos-Polemis Inc	GR	Tsurumi Pump Taiwan Co Ltd	TW
Michael Smith Engineers Ltd	UK	Ebara Corporation	JP	Türbosan AS	TR
Speck-Pumpen	DE	EDUR Pumpenfabrik GmbH & Co KG	DE	Ture International Industrial Ltd	CN
Sulzer Pumps	CH	Franz Eisele und Söhne GmbH & Co KG	DE	Ujala Pumps Pvt Ltd	IN
TKL	AU	Engineered Products Group Pty Ltd (EPG)	AU	Weir Gabbioneta Srl	IT
Torishima Pump Mfg Co Ltd	JP	Ensival-Moret	BE	Weir Pumps Ltd	UK
TriVista Engineering Ltd	UK	Fairbanks Morse Pump	US		
Tsurumi (America) Inc	US	Flowserve Corporation	US	NON-METALLIC ROTODYNAMIC PUMPS	
Tsurumi (Europe) GmbH	DE	Flux-Geräte GmbH	DE	Apollo Gössnitz GmbH	DE
Tsurumi (Shanghai) Co Ltd	CN	Goulds Pumps,	US	APV Fluid Handling Horsens	DK
		ITT Industrial & BioPharm Group		Best & Crompton Engineering Ltd	IN

Caprari SpA	IT	AxFlow Ltd	UK	Inoxpa SA	ES
Casals Cardona Industries SA	ES	AxFlow Oy	FI	Iron Pump A/S	DK
Caster HMD Kontro	UK	AxFlow sro	CZ	Kawamoto Pump Manufacturing Co Ltd	JP
Chung Woo Industrial Co Ltd	KR	AxFlow SAS	FR	Klaus Union GmbH & Co KG	DE
Ebara Corporation	JP	AxFlow SAS	ES	Laxmi Hydraulics Pvt Ltd	IN
EBS-Ray Pumps Pty Ltd	AU	AxFlow Sp Soo	PL	Lederle GmbH	DE
EDUR Pumpenfabrik GmbH & Co KG	DE	AxFlow SpA	IT	Liverani Srl	IT
Finish Thompson Inc	US	Catag AG	CH	Lowara SpA, ITT Industries	IT
Invensys APV	US	Cornell	US	Magnatex Pumps Inc	US
Invensys APV UK	UK	Discflo Corporation	US	March May Ltd	UK
Kelair Pumps Australia Pty Ltd	AU	Ebara Corporation	JP	Mepco	US
Kestner Engineering Co Ltd	UK	EBS-Ray Pumps Pty Ltd	AU	MTH Pumps	US
Oy Kolmeks AB	FI	EDUR Pumpenfabrik GmbH & Co KG	DE	Paco Pumps	US
KSB Ltd	UK	Flexachem Manufacturing Ltd	IE	Pumpenfabrik Ernst Vogel GmbH, ITT Industries	IT
Lederle GmbH	DE	Flotronic Pumps Ltd	UK	Pulsafeeder	US
London Pumps Ltd	UK	Fluid Metering Inc	US	Raj Pumps	IN
MASO Process-Pumpen GmbH	DE	Flux-Geräte GmbH	DE	Rapid Allweiler Pump & Engineering	ZA
Mefiag Division, Met-Pro Corporation	US	Fristam Pumps (UK) Ltd	UK	Roth Pump Company	US
Paco Pumps	US	Fristam Pumps USA	US	Rütschi Fluid AG	CH
Peerless Pump Company	US	Fristam Pumpen	DE	SAWA Pumpentechnik AG	CH
PT Ebara Indonesia	ID	Philipp Hilge GmbH & Co KG	DE	Scheerle AG	CH
Pump & Package Ltd	UK	Hilge Pumps Ltd	UK	Schmalenberger GmbH & Co	DE
Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA	Hunan XD Changsha Pump Works Co Ltd	CN	Sero PumpSystems GmbH	DE
Roth Pump Company	US	Inoxpa SA	ES	Sharp Trendys	IN
Ruhrpumpen GmbH	DE	Invensys APV	US	Simaco Elettromeccanica Srl	IT
Ruhrpumpen Inc	US	Invensys APV UK	UK	Sterling Fluid Systems (Americas) Inc	US
Sacem SpA	IT	Johnson Pump (UK) Ltd	UK	Sterling Fluid Systems (Austria)	AT
Savino Barbera	IT	JP Pumps Ltd	UK	Sterling Fluid Systems (Belgium) NV	BE
Schmalenberger GmbH & Co	DE	Kecol Pumps Ltd	UK	Sterling Fluid Systems (France) SAS	FR
Sethco Division, Met-Pro Corporation	US	Kelair Pumps Australia Pty Ltd	AU	Sterling Fluid Systems (Italy) SpA	IT
Sigma Group AS	CZ	Kishor Pumps Ltd	IN	Sterling Fluid Systems (Netherlands)	NL
Sterling Fluid Systems (Americas) Inc	US	MDM Pumps Ltd	UK	Sterling Fluid Systems (Schweiz) AG	CH
Sterling Fluid Systems (Austria)	AT	Packo Inox NV	BE	Sterling Fluid Systems (UK) Ltd	UK
Sterling Fluid Systems (Belgium) NV	BE	Paco Pumps	US	Sterling SIHI GmbH	DE
Sterling Fluid Systems (France) SAS	FR	Pomac Industries Group	NL	Swidnicka Fabryka Pomp Sp Z.o.o.	PL
Sterling Fluid Systems (Italy) SpA	IT	Pump Engineering Ltd	UK	Totton Pumps Ltd	UK
Sterling Fluid Systems (Netherlands)	NL	Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA	Stuart Turner Ltd	UK
Sterling Fluid Systems (Schweiz) AG	CH	Sharp Trendys	IN	Ujala Pumps Pvt Ltd	IN
Sterling Fluid Systems (UK) Ltd	UK	Sigma Group AS	CZ	Verder Group	NL
Sterling SIHI GmbH	DE	Tapflo AB	SE	Wernert-Pumpen GmbH	DE
Sundyne Corporation	US	Verder Group	NL		
Sundyne International SA	FR	Viking Pump Inc	US	PITOT TUBE PUMPS	
Swidnicka Fabryka Pomp Sp Z.o.o.	PL	Pumpenfabrik Wangen GmbH	DE	Ebara Corporation	JP
TKL	AU	Waukesha Cherry-Burrell	US	Sterling Fluid Systems (Americas) Inc	US
Ujala Pumps Pvt Ltd	IN	Wright Pump	US	Sterling Fluid Systems (Austria)	AT
Verder Group	NL			Sterling Fluid Systems (Belgium) NV	BE
Waterman Industries Ltd	IN	PERIPHERAL PUMPS		Sterling Fluid Systems (France) SAS	FR
Wernert-Pumpen GmbH	DE	Beresford Pumps	UK	Sterling Fluid Systems (Italy) SpA	IT
HYGIENIC-QUALITY ROTODYNAMIC PUMPS		Ceetak Engineering Ltd	UK	Sterling Fluid Systems (Netherlands)	NL
Alfa Laval AB	SE	Chemvac Pumps Ltd	UK	Sterling Fluid Systems (Schweiz) AG	CH
Alfa Laval Inc	US	Corken Inc	US	Sterling Fluid Systems (UK) Ltd	UK
APV Fluid Handling Horsens	DK	Crane Pumps & Systems	US	Sterling SIHI GmbH	DE
Asco Pompe srl	IT	DAB Pumps SpA	IT	Weir Specialty Pumps	US
AxFlow A/S	DK	Davey Products Pty Ltd	AU		
AxFlow AB	SE	DDA Srl	IT	DISC PUMPS	
AxFlow AS	NO	Ebara Corporation	JP	Alfa Laval AB	SE
AxFlow BeNeLux BV	NL	EBS-Ray Pumps Pty Ltd	AU	Alfa Laval Inc	US
AxFlow GmbH	AT	EDUR Pumpenfabrik GmbH & Co KG	DE	Alfa Laval Pumps Ltd	UK
AxFlow GmbH	DE	Fristam Pumps (UK) Ltd	UK	AxFlow A/S	DK
AxFlow GmbH	CH	Fristam Pumps USA	US	AxFlow AB	SE
Axflow Holding AB	SE	Fristam Pumpen	DE	AxFlow AS	NO
AxFlow Kft	HU	Gilbert Gilkes & Gordon Ltd	UK	AxFlow BeNeLux BV	NL
AxFlow Ida	PL	GMP SpA	IT	AxFlow GmbH	AT
AxFlow Ltd	IE	Gysi Pumpen AG	CH	AxFlow GmbH	DE
		Philipp Hilge GmbH & Co KG	DE	AxFlow GmbH	CH
		Hung Pump Industrial Co Ltd	TW	Axflow Holding AB	SE

AxFlow Kft	HU	Dickow Pumpen KG	DE	AxFlow AB	SE
AxFlow Ida	PL	Ebara Corporation	JP	AxFlow AS	NO
AxFlow Ltd	IE	Ebara Fluid Handling	US	AxFlow BeNeLux BV	NL
AxFlow Ltd	UK	Ebara Pumps Europe SpA	IT	AxFlow GmbH	AT
AxFlow Oy	FI	Environamics Corporation	US	AxFlow GmbH	DE
AxFlow sro	CZ	Finish Thompson Inc	US	AxFlow GmbH	CH
AxFlow SAS	FR	Flowserve Corporation	US	Axflow Holding AB	SE
AxFlow SAS	ES	Goulds Pumps,	US	AxFlow Kft	HU
AxFlow Sp Soo	PL	ITT Industrial & BioPharm Group		AxFlow Ida	PL
AxFlow SpA	IT	Gysi Pumpen AG	CH	AxFlow Ltd	IE
Camaction Avonpump Ltd	UK	Herborner Pumpenfabrik	DE	AxFlow Ltd	UK
Crane Pumps & Systems	US	Iwaki America	US	AxFlow Oy	FI
Desmi GmbH	DE	Iwaki Co Ltd	JP	AxFlow sro	CZ
Ebara Corporation	JP	Iwaki Europe GmbH	DE	AxFlow SAS	FR
Ebara Fluid Handling	US	Jiangsu Haishi Pump Co Ltd	CN	AxFlow SAS	ES
Ebara Pumps Europe SpA	IT	Johnson Pump (India), ATE Enterprises Ltd	IN	AxFlow Sp Soo	PL
Fristam Pumps (UK) Ltd	UK	Johnson Pump AB	SE	AxFlow SpA	IT
Fristam Pumps USA	US	Johnson Pump BV	NL	Buffalo Pumps Inc	US
Fristam Pumpen	DE	Johnson Pumps of America Inc	US	Caprari SpA	IT
Hidrotecar SA	ES	Kinder-Janes Engineers Ltd	UK	Caster HMD Kontro	UK
Hilge Pumps Ltd	UK	Klaus Union GmbH & Co KG	DE	Ceetak Engineering Ltd	UK
Sterling Fluid Systems (Americas) Inc	US	KSB Ltd	UK	Chempump	US
Sterling Fluid Systems (Austria)	AT	Lederle GmbH	DE	Cougar Industries Ltd	UK
Sterling Fluid Systems (Belgium) NV	BE	Little Giant Pump Company	US	CW-EMD	US
Sterling Fluid Systems (France) SAS	FR	Lutz (UK) Ltd	UK	Dalian Danai Pumps Ltd	CN
Sterling Fluid Systems (Italy) SpA	IT	Magnatex Pumps Inc	US	Ebara Corporation	JP
Sterling Fluid Systems (Netherlands)	NL	March May Ltd	UK	Ebara Fluid Handling	US
Sterling Fluid Systems (Schweiz) AG	CH	MASO Process-Pumpen GmbH	DE	Ebara Pumps Europe SpA	IT
Sterling Fluid Systems (UK) Ltd	UK	Mefiag Division, Met-Pro Corporation	US	Environamics Corporation	US
Sterling SIHI GmbH	DE	Nova Magnetics Burgmann Ltd	CA	Hayward Tyler® Group	UK
Weir Gabbioneta Srl	IT	Omel Ltda	BR	Hunan XD Changsha Pump Works Co Ltd	CN
MAGNETIC DRIVE ROTODYNAMIC PUMPS		Pacer Pumps	US	Kinder-Janes Engineers Ltd	UK
Acromet (Aust) Pty Ltd	AU	Pomac Industries Group	NL	MASO Process-Pumpen GmbH	DE
Allweiler AG	DE	Price Pump Company	US	Mazda Pump Manufacturing Co Ltd	JP
Ansimag Inc	US	Pump Engineering Ltd	UK	MTH Pumps	US
Argal Srl	IT	Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA	Nikkiso Co Ltd	JP
AxFlow A/S	DK	Roth Pump Company	US	Nikkiso Pumps Europe GmbH	DE
AxFlow AB	SE	Savino Barbera	IT	Optimex	FR
AxFlow AS	NO	Serfilco Europe Ltd	UK	Rütschi Fluid AG	CH
AxFlow BeNeLux BV	NL	Serfilco Ltd	US	Michael Smith Engineers Ltd	UK
AxFlow GmbH	AT	Sero PumpSystems GmbH	DE	Sundyne Corporation	US
AxFlow GmbH	DE	Sethco Division, Met-Pro Corporation	US	Sundyne International SA	FR
AxFlow GmbH	CH	Michael Smith Engineers Ltd	UK	Teikoku Electric GmbH	DE
Axflow Holding AB	SE	Sterling Fluid Systems (Americas) Inc	US	Termomeccanica Pompe SpA	IT
AxFlow Kft	HU	Sterling Fluid Systems (Austria)	AT	3S Systemtechnik AG	CH
AxFlow Ida	PL	Sterling Fluid Systems (Belgium) NV	BE	TKL	AU
AxFlow Ltd	IE	Sterling Fluid Systems (France) SAS	FR	Wilo AG	DE
AxFlow Ltd	UK	Sterling Fluid Systems (Italy) SpA	IT	Wilo EMU GmbH	DE
AxFlow Oy	FI	Sterling Fluid Systems (Netherlands)	NL	Yaltek AS	TR
AxFlow sro	CZ	Sterling Fluid Systems (Schweiz) AG	CH	ROTODYNAMIC PUMPS WITHOUT DRIVERS (for specific applications including mobile agricultural applications and mobile fire pumps)	
AxFlow SAS	FR	Sterling Fluid Systems (UK) Ltd	UK	Caprari SpA	IT
AxFlow SAS	ES	Sterling SIHI GmbH	DE	Darley Pumps	US
AxFlow Sp Soo	PL	Sundyne Corporation	US	Sunmotor International Ltd	CA
AxFlow SpA	IT	Sundyne International SA	FR	TKL	AU
Beresford Pumps	UK	Sunmotor International Ltd	CA	Albert Ziegler GmbH & Co KG	DE
Cakasa (Nigeria) Co Ltd	NG	Tapflo AB	SE	PUMPS AS POWER-RECOVERY TURBINES	
Carver Pump Company	US	TKL	AU	Flowserve Corporation	US
Caster HMD Kontro	UK	Totton Pumps Ltd	UK	Goulds Pumps,	US
Catag AG	CH	TriVista Engineering Ltd	UK	ITT Industrial & BioPharm Group	
CDR Pompe SpA	IT	Varisco Srl	IT	Termomeccanica Pompe SpA	IT
Ceetak Engineering Ltd	UK	Verder Group	NL	TriVista Engineering Ltd	UK
Chempump	US	Victor Pumpen GmbH	DE	Pumpenfabrik Ernst Vogel GmbH,	AT
Chemvac Pumps Ltd	UK	Weir Gabbioneta Srl	IT	ITT Industries	
CP Pumpen AG	CH	CANNED MOTOR ROTODYNAMIC PUMPS			
Dalian Danai Pumps Ltd	CN	AxFlow A/S	DK		

18.4 Positive displacement pumps

Companies listed alphabetically by pump type

EXTERNAL GEAR PUMPS

Albany Engineering Company Ltd	UK
Allpumps Ltd	UK
Asco Pompe srl	IT
AxFlow A/S	DK
AxFlow AB	SE
AxFlow AS	NO
AxFlow BeNeLux BV	NL
AxFlow GmbH	AT
AxFlow GmbH	DE
AxFlow GmbH	CH
Axflow Holding AB	SE
AxFlow Kft	HU
AxFlow Ida	PL
AxFlow Ltd	IE
AxFlow Ltd	UK
AxFlow Oy	FI
AxFlow sro	CZ
AxFlow SAS	FR
AxFlow SAS	ES
AxFlow Sp Soo	PL
AxFlow SpA	IT
Bielomatik Leuze GmbH & Co	DE
Bornemann GmbH	DE
Cakasa (Nigeria) Co Ltd	NG
Catag AG	CH
Colfax Pump Group	US
Concentric Pumps Ltd	UK
Cross Manufacturing Inc	US
Pompe Cucchi Srl	IT
Ebara Corporation	JP
EBS-Ray Pumps Pty Ltd	AU
Engineered Products Group Pty Ltd (EPG)	AU
Finder Pompe SpA	IT
Flowserve Corporation	US
Gilbert Gilkes & Gordon Ltd	UK
Haight Pumps	US
Honda Kiko Co Ltd	JP
Hung Pump Industrial Co Ltd	TW
Hypro	US
Ismatec SA	CH
Iwaki Co Ltd	JP
Iwaki Europe GmbH	DE
Kracht GmbH	DE
Lederle GmbH	DE
Lewis Pumps	US
London Pumps Ltd	UK
Maag Pump Systems Textron AG	CH
Maag Pump Systems Textron Inc	US
Mather & Platt Pumps Ltd	IN
Micropump Ltd	UK
Midland Pump Manufacturing Co Ltd	UK
Northern Pump	US
Nova Magnetis Burgmann Ltd	CA
Pedro Roquet SA	ES
Pulsafeeder	US
Pump Engineering Co Pvt Ltd	IN
Pump Engineering Ltd	UK
Rickmeier GmbH	DE
Scherzinger Pumps	DE
Shin Shin Machinery Co Ltd	KR

Sigma Group AS	CZ
Michael Smith Engineers Ltd	UK
Tuschaco Pumps Ltd	IN
Tuthill Corporation	US
Variopumps Pumpenbau GmbH	DE
Varisco Srl	IT
Viking Pump Inc	US
Witte Pumps & Technology GmbH	DE
Zenith Pumps Division, Parker Hannifin	US

INTERNAL GEAR PUMPS

Acromet (Aust) Pty Ltd	AU
Asco Pompe srl	IT
AxFlow A/S	DK
AxFlow AB	SE
AxFlow AS	NO
AxFlow BeNeLux BV	NL
AxFlow GmbH	AT
AxFlow GmbH	DE
AxFlow GmbH	CH
Axflow Holding AB	SE
AxFlow Kft	HU
AxFlow Ida	PL
AxFlow Ltd	IE
AxFlow Ltd	UK
AxFlow Oy	FI
AxFlow sro	CZ
AxFlow SAS	FR
AxFlow SAS	ES
AxFlow Sp Soo	PL
AxFlow SpA	IT
Bavaria Fluidtec GmbH	DE
Bijur Lubricating Corporation	US
Catag AG	CH
CDS-John Blue Company	US
Ceetac Engineering Ltd	UK
Chemvac Pumps Ltd	UK
Colfax Pump Group	US
Concentric Pumps Ltd	UK
Cougar Industries Ltd	UK
Desmi A/S	DK
Desmi GmbH	DE
EBS-Ray Pumps Pty Ltd	AU
Engineered Products Group Pty Ltd (EPG)	AU
Flexachem Manufacturing Ltd	IE
Fultz Pumps Inc	US
Pompe Garbarino SpA	IT
Gorman-Rupp Company	US
Gotec SA	CH
Haight Pumps	US
Honda Kiko Co Ltd	JP
Indag Maschinenbau GmbH	DE
Ismatec SA	CH
Iwaki America	US
JLS International (UK) Ltd	UK
Johnson Pump (India), ATE Enterprises Ltd	IN
Johnson Pump AB	SE
Johnson Pump BV	NL
Johnson Pumps of America Inc	US
JP Pumps Ltd	UK
Kecol Pumps Ltd	UK
Kelair Pumps Australia Pty Ltd	AU

Kinder-Janes Engineers Ltd	UK
Lederle GmbH	DE
Lobee Pump & Machinery Company	US
London Pumps Ltd	UK
Mahr Metering Systems Corporation	US
Matra SpA	IT
Micropump Inc	US
Pulsafeeder	US
Pump & Package Ltd	UK
SAWA Pumpentechnik AG	CH
Scherzinger Pumps	DE
Sigma Group AS	CZ
Michael Smith Engineers Ltd	UK
Sterling Fluid Systems (Americas) Inc	US
Sterling Fluid Systems (Austria)	AT
Sterling Fluid Systems (Belgium) NV	BE
Sterling Fluid Systems (France) SAS	FR
Sterling Fluid Systems (Italy) SpA	IT
Sterling Fluid Systems (Netherlands)	NL
Sterling Fluid Systems (Schweiz) AG	CH
Sterling Fluid Systems (UK) Ltd	UK
Sterling SIHI GmbH	DE
Taiko Kikai Industries Co Ltd	JP
TKL	AU
TriVista Engineering Ltd	UK
Tuschaco Pumps Ltd	IN
Tuthill Corporation	US
Variopumps Pumpenbau GmbH	DE
Varisco Srl	IT
Verder Group	NL
Pompe Vergani	IT
Vican Pump Company	CA
Victor Pumpen GmbH	DE
Viking Pump Inc	US

ARCHIMEDES SCREW PUMPS

Allpumps Ltd	UK
Asco Pompe srl	IT
Cakasa (Nigeria) Co Ltd	NG
Cole-Parmer Instrument Company	US
Defco	US
Delasco PCM GmbH	DE
Engineered Products Group Pty Ltd	AU
Ensival-Moret	BE
Houttuin Holland BV	NL
Imo AB	SE
Bombas Itur SA	ES
Bombas Itur SA	ES
Jiangsu Haishi Pump Co Ltd	CN
Kräutler GmbH & Co	AT
Leistritz Pumpen GmbH	DE
Sigma Group AS	CZ
Spaans Babcock BV	NL
Tianjin Pumps & Machinery Group Co Ltd	CN
Vandezande	BE
Verder Group	NL
Weir Minerals Division	US

TWIN-ROTOR SCREW PUMPS

Allweiler AG	DE
Asco Pompe srl	IT
AxFlow A/S	DK

AxFlow AB	SE	AxFlow SAS	FR	Sigma Group AS	CZ
AxFlow AS	NO	AxFlow SAS	ES	Spaans Babcock BV	NL
AxFlow BeNeLux BV	NL	AxFlow Sp Soo	PL	Tianjin Pumps & Machinery Group Co Ltd	CN
AxFlow GmbH	AT	AxFlow SpA	IT	Tyco - Southern Cross Plant	AU
AxFlow GmbH	DE	BOC Edwards - Hick Hargreaves	UK	Vandezande	BE
AxFlow GmbH	CH	Bornemann GmbH	DE	Pumpenfabrik Wangen GmbH	DE
Axflow Holding AB	SE	Colfax Pump Group	US	Warren Pumps LLC	US
AxFlow Kft	HU	DDA Srl	IT	Weir Minerals Division	US
AxFlow Ida	PL	Desmi A/S	DK	Weir Specialty Pumps	US
AxFlow Ltd	IE	Engineered Products Group Pty Ltd	AU	PROGRESSIVE CAVITY PUMPS	
AxFlow Ltd	UK	Engineered Products Group Pty Ltd (EPG)	AU	Alfa Laval AB	SE
AxFlow Oy	FI	Ensival-Moret	BE	Alfa Laval Inc	US
AxFlow sro	CZ	Flux-Geräte GmbH	DE	AxFlow A/S	DK
AxFlow SAS	FR	Houttuin Holland BV	NL	AxFlow AB	SE
AxFlow SAS	ES	Imo AB	SE	AxFlow AS	NO
AxFlow Sp Soo	PL	Bombas Itur SA	ES	AxFlow BeNeLux BV	NL
AxFlow SpA	IT	Iwaki Co Ltd	JP	AxFlow GmbH	AT
Bornemann GmbH	DE	Iwaki Europe GmbH	DE	AxFlow GmbH	DE
Cole-Parmer Instrument Company	US	Kelair Pumps Australia Pty Ltd	AU	AxFlow GmbH	CH
Colfax Pump Group	US	Kinder-Janes Engineers Ltd	UK	Axflow Holding AB	SE
Defco	US	Klaus Union GmbH & Co KG	DE	AxFlow Kft	HU
Delasco PCM GmbH	DE	Kräutler GmbH & Co	AT	AxFlow Ida	PL
Engineered Products Group Pty Ltd	AU	Leistritz Pumpen GmbH	DE	AxFlow Ltd	IE
Ensival-Moret	BE	Nova Magnetics Burgmann Ltd	CA	AxFlow Ltd	UK
Flowserve Corporation	US	Peerless Pump Company	US	AxFlow Oy	FI
Hidrotecar SA	ES	Plenty Mirreles Pumps	UK	AxFlow sro	CZ
Houttuin Holland BV	NL	Pomac Industries Group	NL	AxFlow SAS	FR
Imo AB	SE	Rapid Allweiler Pump & Engineering	ZA	AxFlow SAS	ES
Bombas Itur SA	ES	Roper Pump Company	US	AxFlow Sp Soo	PL
Bombas Itur SA	ES	Roto Pumps Ltd	IN	AxFlow SpA	IT
Iwaki Co Ltd	JP	Scheerle AG	CH	Bavaria Fluidtec GmbH	DE
Iwaki Europe GmbH	DE	Sigma Group AS	CZ	Catag AG	CH
Jiangsu Haishi Pump Co Ltd	CN	Spaans Babcock BV	NL	Cole-Parmer Instrument Company	US
Kräutler GmbH & Co	AT	Tianjin Pumps & Machinery Group Co Ltd	CN	Colfax Pump Group	US
Leistritz Pumpen GmbH	DE	Tyco - Southern Cross Plant	AU	Continental Pump Company	US
Moyno Inc	US	Vandezande	BE	Cougar Industries Ltd	UK
Nova Magnetics Burgmann Ltd	CA	Willy Vogel AG	DE	Dalian Danaï Pumps Ltd	CN
Plenty Mirreles Pumps	UK	Pumpenfabrik Wangen GmbH	DE	Denorco (Pty) Ltd	ZA
Pomac Industries Group	NL	Weir Minerals Division	US	Eagle Pump & Compressor Ltd	CA
Rapid Allweiler Pump & Engineering	ZA	Weir Pumps Ltd	UK	Equimavenca	VE
Roper Pump Company	US	Weir Specialty Pumps	US	Flexachem Manufacturing Ltd	IE
Roto Pumps Ltd	IN	TWIN-ROTOR GEARED — SCREW PUMPS		Flojet Corporation	US
Scheerle AG	CH	Allweiler AG	DE	Flux Pumps Corporation	US
Sigma Group AS	CZ	BOC Edwards - Hick Hargreaves	UK	Pompe Garbarino SpA	IT
Spaans Babcock BV	NL	Bornemann GmbH	DE	Inoxpa SA	ES
Tianjin Pumps & Machinery Group Co Ltd	CN	Desmi A/S	DK	ITT Flygt AB	SE
Vandezande	BE	Engineered Products Group Pty Ltd (EPG)	AU	Johnson Pump (India), ATE Enterprises Ltd	IN
Warren Pumps LLC	US	Ensival-Moret	BE	Johnson Pump AB	SE
Weir Minerals Division	US	Flowserve Corporation	US	Johnson Pump BV	NL
TWIN-ROTOR & 5-ROTOR SCREW PUMPS		Flux Pumps Corporation	US	Johnson Pumps of America Inc	US
Allweiler AG	DE	Flux-Geräte GmbH	DE	Kächele GmbH	DE
AxFlow A/S	DK	Hidrotecar SA	ES	Kelair Pumps Australia Pty Ltd	AU
AxFlow AB	SE	Houttuin Holland BV	NL	Kinder-Janes Engineers Ltd	UK
AxFlow AS	NO	Imo AB	SE	Kudu Industries Inc	CA
AxFlow BeNeLux BV	NL	Bombas Itur SA	ES	Mono Pumps (Australia) Pty Ltd	AU
AxFlow GmbH	AT	Iwaki Co Ltd	JP	Mono Pumps (China) Ltd	CN
AxFlow GmbH	DE	Iwaki Europe GmbH	DE	Mono Pumps (New Zealand) Ltd	NZ
AxFlow GmbH	CH	Klaus Union GmbH & Co KG	DE	Mono Pumps Ltd	UK
Axflow Holding AB	SE	Kräutler GmbH & Co	AT	Monoflo Inc	US
AxFlow Kft	HU	Leistritz Pumpen GmbH	DE	Moyno Inc	US
AxFlow Ida	PL	Peerless Pump Company	US	Netzsch Mohnopumpen GmbH	DE
AxFlow Ltd	IE	Plenty Mirreles Pumps	UK	PCM	FR
AxFlow Ltd	UK	Rapid Allweiler Pump & Engineering	ZA	PCM Asia Pacific	CN
AxFlow Oy	FI	Roto Pumps Ltd	IN	PCM Delasco GmbH	DE
AxFlow sro	CZ	Scheerle AG	CH	PCM Delasco Inc	US

PCM Moineau Oilfield	CN	Flojet Corporation	US	AxFlow Sp Soo	PL
PCM Pompes Russia	RU	GPM Pumps Inc	US	AxFlow SpA	IT
PCM Pompes Thailand	TH	Philipp Hilge GmbH & Co KG	DE	Barnant Company	US
PCM Pumps Ltd	UK	Invensys APV	US	BOC Edwards - Hick Hargreaves	UK
PCM Tunisia	TN	Invensys APV UK	UK	Caster HMD Kontro	UK
Peerless Pump Company	US	Jabsco GmbH, ITT Industries	DE	Ceetac Engineering Ltd	UK
PF Pumpen und Feuerlöschtechnik GmbH	DE	Jabsco UK, ITT Industries	UK	Corken Inc	US
Pump & Package Ltd	UK	Jabsco US, ITT Industries	US	Dalian Danai Pumps Ltd	CN
Rapid Allweiler Pump & Engineering	ZA	Johnson Pump (India), ATE Enterprises Ltd	IN	EBS-Ray Pumps Pty Ltd	AU
Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA	Johnson Pump (UK) Ltd	UK	Flojet Corporation	US
Roper Pump Company	US	Johnson Pump AB	SE	GMP SpA	IT
Roto Pumps Ltd	IN	Johnson Pump BV	NL	Gotec SA	CH
Rotomac Industires Pvt Ltd	IN	Johnson Pumps of America Inc	US	Graham Vacuum Pumps Ltd	UK
Scheerle AG	CH	JP Pumps Ltd	UK	Gysi Pumpen AG	CH
seepex GmbH & Co KG	DE	Jurop SpA	IT	Hunan XD Changsha Pump Works Co Ltd	CN
seepex UK Ltd	UK	Kelair Pumps Australia Pty Ltd	AU	Hypso	US
Sigma Group AS	CZ	Kielecka Fabryka Pomp Bialogon SA	PL	Jabsco GmbH, ITT Industries	DE
Sigmia Trading International	CZ	Kudu Industries Inc	CA	Jabsco UK, ITT Industries	UK
Standard Pump Inc	US	Lederle GmbH	DE	Jabsco US, ITT Industries	US
Taiko Kikai Industries Co Ltd	JP	Lutz-Jesco	DE	Johnson Pump (India), ATE Enterprises Ltd	IN
Tarby Inc	US	Megator Ltd	UK	Johnson Pump AB	SE
Tyco - Southern Cross Plant	AU	Netzsch Mohnopumpen GmbH	DE	Johnson Pump BV	NL
Varisco Srl	IT	Omac Srl	IT	Johnson Pumps of America Inc	US
Verder Group	NL	PCM	FR	Lederle GmbH	DE
Pumpenfabrik Wangen GmbH	DE	PCM Asia Pacific	CN	Liverani Srl	IT
Warren Pumps LLC	US	PCM Delasco GmbH	DE	MASO Process-Pumpen GmbH	DE
Witte Pumps & Technology GmbH	DE	PCM Delasco Inc	US	Monarch Industries Ltd	CA
Yaltek AS	TR	PCM Moineau Oilfield	CN	Pentair Inc	US
LOBE PUMPS —		PCM Pompes Russia	RU	Pentair Pumps SpA	IT
(including circumferential piston pumps)		PCM Pompes Thailand	TH	Pomac Industries Group	NL
Alfa Laval AB	SE	PCM Pumps Ltd	UK	Procon Products	US
Alfa Laval Inc	US	PCM Tunisia	TN	Pulsafeeder	US
Alfa Laval Pumps Ltd	UK	Pentair Inc	US	Pump & Package Ltd	UK
Alfons de Backer & Co	BE	Pentair Pumps SpA	IT	Pump Engineering Ltd	UK
Allpumps Ltd	UK	Plenty Mirreles Pumps	UK	Rietschle Thomas Schopfheim GmbH	DE
APV Fluid Handling Horsens	DK	Pomac Industries Group	NL	SHURflo Pump Manufacturing Co	US
Asco Pompe srl	IT	Roper Pump Company	US	Sigma Group AS	CZ
AxFlow A/S	DK	Scherzinger Pumps	DE	Sundyne Corporation	US
AxFlow AB	SE	Sigma Group AS	CZ	Sundyne International SA	FR
AxFlow AS	NO	Sigmia Trading International	CZ	3S Systemtechnik AG	CH
AxFlow BeNeLux BV	NL	Tuschaco Pumps Ltd	IN	TriVista Engineering Ltd	UK
AxFlow GmbH	AT	Tuthill Corporation	US	Verder Group	NL
AxFlow GmbH	DE	Verder Group	NL	PERISTALTIC PUMPS —	
AxFlow GmbH	CH	Viking Pump Inc	US	(including rotary peristaltic pumps)	
Axflow Holding AB	SE	Waukesha Cherry-Burrell	US	Acromet (Aust) Pty Ltd	AU
AxFlow Kft	HU	VANE PUMPS		Allpumps Ltd	UK
AxFlow Ida	PL	Alfons Haar Maschinenbau GmbH & Co	DE	Allweiler AG	DE
AxFlow Ltd	IE	Allpumps Ltd	UK	Asco Pompe srl	IT
AxFlow Ltd	UK	A-Ryung Machinery Ind Co Ltd	KR	Autoclave Pumps	UK
AxFlow Oy	FI	AxFlow A/S	DK	AxFlow A/S	DK
AxFlow sro	CZ	AxFlow AB	SE	AxFlow AB	SE
AxFlow SAS	FR	AxFlow AS	NO	AxFlow AS	NO
AxFlow SAS	ES	AxFlow BeNeLux BV	NL	AxFlow BeNeLux BV	NL
AxFlow Sp Soo	PL	AxFlow GmbH	AT	AxFlow GmbH	AT
AxFlow SpA	IT	AxFlow GmbH	DE	AxFlow GmbH	DE
BOC Edwards - Hick Hargreaves	UK	AxFlow GmbH	CH	AxFlow GmbH	CH
Börger GmbH	DE	Axflow Holding AB	SE	Axflow Holding AB	SE
Catag AG	CH	AxFlow Kft	HU	AxFlow Kft	HU
Ceetac Engineering Ltd	UK	AxFlow Ida	PL	AxFlow Ida	PL
Concentric Pumps Ltd	UK	AxFlow Ltd	IE	AxFlow Ltd	IE
Pompe Cucchi Srl	IT	AxFlow Ltd	UK	AxFlow Ltd	UK
EBS-Ray Pumps Pty Ltd	AU	AxFlow Oy	FI	AxFlow Oy	FI
Engineered Products Group Pty Ltd (EPG)	AU	AxFlow sro	CZ	AxFlow sro	CZ
Equimavenca	VE	AxFlow SAS	FR	AxFlow SAS	FR
Finder Pompe SpA	IT	AxFlow SAS	ES	AxFlow SAS	ES

AxFlow Sp Soo	PL	Bombas Itur SA	ES	DESCALING PUMPS	
AxFlow SpA	IT	Korina Pumps	GR	RMI Pressure Systems Ltd	UK
Barnant Company	US	Motorrens SL	ES	Toyo Pumps Europe	BE
Beta Technology Inc	US	National Oilwell Varco	USA	Uraca Pumpenfabrik GmbH & Co KG	DE
Blue White Industries	US	Putzmeister Ltd	UK	PLUNGER PUMPS	
Bombas Boyser SL	ES	Ragazzini Srl	IT	(includes horizontal and vertical)	
Bredel Hose Pumps	NL	Sigmia Trading International	CZ	Aldos Ltd	UK
Catag AG	CH	TKL	AU	Annovireverberi SpA	IT
Ceetak Engineering Ltd	UK	TriVista Engineering Ltd	UK	Benxi Water Pump Factory	CN
Cole-Parmer Instrument Company	US	Wheatley and Gaso Pump	US	Bühler Hochdrucktechnik GmbH	AT
Colfax Pump Group	US	Wright Pump	US	CAT Pumps	US
Crane Process Flow Technologies Ltd	UK	INLINE PISTON PUMPS		CAT Pumps (UK) Ltd	UK
DDA Srl	IT	ACD Cryo GmbH	DE	Dawson Downie Lamont	UK
Defco	US	Alfons de Backer & Co	BE	DDA Srl	IT
Delasco PCM GmbH	DE	Bavaria Fluidtec GmbH	DE	Equimavenca	VE
Equimavenca	VE	BBA Hranice sro	CZ	Flowserve Corporation	US
Finder Pompe SpA	IT	Bielomatik Leuze GmbH & Co	DE	Gysi Pumpen AG	CH
Flexicon A/S	DK	Bühler Hochdrucktechnik GmbH	AT	Hauhincó	DE
GPM Pumps Inc	US	CAT Pumps	US	Imovilli Pompe Srl	IT
Johnson Pump (India), ATE Enterprises Ltd	IN	CAT Pumps (UK) Ltd	UK	Ingersoll-Rand/ARO	US
Johnson Pump AB	SE	Catag AG	CH	Kamat Pumpen GmbH Co KG	DE
Johnson Pump BV	NL	Chempump	US	Kudu Industries Inc	CA
Johnson Pumps of America Inc	US	Chemvac Pumps Ltd	UK	LMI Milton Roy	US
JP Pumps Ltd	UK	Cougar Industries Ltd	UK	Milton Roy Europe	FR
Kecol Pumps Ltd	UK	Fluid Metering Inc	US	National Oilwell Varco	USA
Kudu Industries Inc	CA	Framo Engineering AS	NO	PCM	FR
Lutz-Jesco	DE	Gzut SA Pumps Department	PL	PCM Asia Pacific	CN
PCM	FR	Hauhincó	DE	PCM Delasco GmbH	DE
PCM Asia Pacific	CN	Heypac Ltd	UK	PCM Delasco Inc	US
PCM Delasco GmbH	DE	Hidrotecar SA	ES	PCM Moineau Oilfield	CN
PCM Delasco Inc	US	Horn GmbH & Co KG	DE	PCM Pompes Russia	RU
PCM Moineau Oilfield	CN	Ingersoll-Rand/ARO	US	PCM Pompes Thailand	TH
PCM Pompes Russia	RU	Iron Pump A/S	DK	PCM Pumps Ltd	UK
PCM Pompes Thailand	TH	Bombas Itur SA	ES	PCM Tunisia	TN
PCM Pumps Ltd	UK	Jensen	US	Peroni Pompe SpA	IT
PCM Tunisia	TN	Kamat Pumpen GmbH Co KG	DE	ProMinent Dosiertechnik GmbH	DE
PF Pumpen und Feuerlöschtechnik GmbH	DE	Komline-Sanderson	US	ProMinent Fluid Controls UK Ltd	UK
ProMinent Dosiertechnik GmbH	DE	Korina Pumps	GR	RMI Pressure Systems Ltd	UK
ProMinent Fluid Controls UK Ltd	UK	Kovoplast Chlumec nad Cidlinou as	CZ	Saint-Gobain Performance Plastics	US
Pump & Package Ltd	UK	Larius Srl	IT	Seko Bono Exacta SpA	IT
Pump Engineering Ltd	UK	Liverani Srl	IT	Seko Ltd	UK
Ragazzini Srl	IT	Metaltchem-Warszawa SA	PL	Seybert & Rahier GmbH	DE
Rapid Allweiler Pump & Engineering	ZA	Motorrens SL	ES	Michael Smith Engineers Ltd	UK
Rietschle Thomas Schopfheim GmbH	DE	Motorrens SL	ES	SPM Flow Control Inc	US
Seko Bono Exacta SpA	IT	National Oilwell Varco	USA	SPX Process Equipment Ltd	UK
Seko Ltd	UK	Nikkiso Co Ltd	JP	Teledyne Isco Inc	US
SHURflo Pump Manufacturing Co	US	Nikkiso Pumps Europe GmbH	DE	Toyo Pumps Europe	BE
Simaco Elettromeccanica Srl	IT	The Oilgear Company	US	Uraca Pumpenfabrik GmbH & Co KG	DE
Verder Group	NL	Peroni Pompe SpA	IT	Verder Group	NL
Wallace & Tiernan, Chemfeed Ltd	UK	Powen Pump Factory Co Ltd	PL	Wallace & Tiernan, Chemfeed Ltd	UK
CH Warman Pump Group	ZA	PreciDose Pumps & Systems	IN	Wanner International Ltd	UK
Watson-Marlow Bredel Pumps Ltd	UK	Putzmeister Ltd	UK	Woma Apparatebau GmbH	DE
ROTARY ECCENTRIC PISTON PUMPS		Ragazzini Srl	IT	Aldos GmbH	DE
Graham Vacuum Pumps Ltd	UK	Saint-Gobain Performance Plastics	US	SYRINGE PUMPS	
Bombas Itur SA	ES	Seybert & Rahier GmbH	DE	KD Scientific Inc	US
Seko Ltd	UK	Sigmia Trading International	CZ	Saint-Gobain Performance Plastics	US
TriVista Engineering Ltd	UK	Taiko Kikai Industries Co Ltd	JP	Seybert & Rahier GmbH	DE
Verder Group	NL	Teledyne Isco Inc	US	Teledyne Isco Inc	US
Waukesha Cherry-Burrell	US	TKL	AU	DIAPHRAGM PUMPS	
Wheatley and Gaso Pump	US	Tuschaco Pumps Ltd	IN	(includes mechanical and hydraulic actuation)	
AXIAL AND RADIAL PISTON PUMPS		Tuthill Corporation	US	Ace Pump Corporation	US
Bavaria Fluidtec GmbH	DE	Wheatley and Gaso Pump	US	Air Pumping Engineering Service	UK
BBA Hranice sro	CZ	Wright Pump	US	Alfa Laval AB	SE
Gzut SA Pumps Department	PL			Alfa Laval Inc	US

Alfa Laval Pumps Ltd	UK	Kudu Industries Inc	CA	Wirth Group	DE
Alfons de Backer & Co	BE	LEWA GmbH	DE	Yaltek AS	TR
Alidos Ltd	UK	Linatex Ltd	UK	Yamada America Inc	US
Alidos GmbH	DE	LMI Milton Roy	US	Yamada Corporation	JP
Allpumps Ltd	UK	Lutz (UK) Ltd	UK	Yamada Europe BV	NL
American Lewa Inc	US	Lutz-Jesco	DE	AIR-OPERATED DOUBLE-DIAPHRAGM PUMPS	
Annovireverberi SpA	IT	Lutz-Jesco America Corporation	US	Alfons de Backer & Co	BE
Asco Pompe srl	IT	Madden Manufacturing Inc	US	Allpumps Ltd	UK
Charles Austen Pumps Ltd	UK	Milton Roy Europe	FR	Alltech Dosieranlagen GmbH	DE
AxFlow A/S	DK	Neptune Chemical Pump Company Inc	US	American Lewa Inc	US
AxFlow AB	SE	Nikkiso Co Ltd	JP	Annovireverberi SpA	IT
AxFlow AS	NO	Nikkiso Pumps Europe GmbH	DE	Asco Pompe srl	IT
AxFlow BeNeLux BV	NL	Omel Ltda	BR	Charles Austen Pumps Ltd	UK
AxFlow GmbH	AT	PCM	FR	AxFlow A/S	DK
AxFlow GmbH	DE	PCM Asia Pacific	CN	AxFlow AB	SE
AxFlow GmbH	CH	PCM Delasco GmbH	DE	AxFlow AS	NO
Axflow Holding AB	SE	PCM Delasco Inc	US	AxFlow BeNeLux BV	NL
AxFlow Kft	HU	PCM Moineau Oilfield	CN	AxFlow GmbH	AT
AxFlow Ida	PL	PCM Pompes Russia	RU	AxFlow GmbH	DE
AxFlow Ltd	IE	PCM Pompes Thailand	TH	AxFlow GmbH	CH
AxFlow Ltd	UK	PCM Pumps Ltd	UK	Axflow Holding AB	SE
AxFlow Oy	FI	PCM Tunisia	TN	AxFlow Kft	HU
AxFlow sro	CZ	Pentair Inc	US	AxFlow Ida	PL
AxFlow SAS	FR	Pentair Pumps SpA	IT	AxFlow Ltd	IE
AxFlow SAS	ES	PreciDose Pumps & Systems	IN	AxFlow Ltd	UK
AxFlow Sp Soo	PL	Price Pump Company	US	AxFlow Oy	FI
AxFlow SpA	IT	ProMinent Dosiertechnik GmbH	DE	AxFlow sro	CZ
Barnant Company	US	ProMinent Fluid Controls UK Ltd	UK	AxFlow SAS	FR
BBA Hranice sro	CZ	Pulsafeeder	US	AxFlow SAS	ES
Benxi Water Pump Factory	CN	Pump & Package Ltd	UK	AxFlow Sp Soo	PL
Ceetak Engineering Ltd	UK	Pump Engineering Ltd	UK	AxFlow SpA	IT
Cole-Parmer Instrument Company	US	Pumper Parts LLC	US	Barnant Company	US
Cougar Industries Ltd	UK	Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA	BBA Hranice sro	CZ
Pompe Cucchi Srl	IT	Rietschle Thomas Schopfheim GmbH	DE	Benxi Water Pump Factory	CN
DDA Srl	IT	Roxspur Measurement & Control Ltd	UK	Catag AG	CH
Equimavenca	VE	Saint-Gobain Performance Plastics	US	CDS-John Blue Company	US
Flexachem Manufacturing Ltd	IE	Savino Barbera	IT	Ceetak Engineering Ltd	UK
Flotronic Pumps Ltd	UK	Seko Bono Exacta SpA	IT	Chem Resist Group Ltd	UK
Flux-Geräte GmbH	DE	Seko Ltd	UK	Chempump	US
Framo Engineering AS	NO	Serfilco Europe Ltd	UK	Cole-Parmer Instrument Company	US
Gilbert Gilkes & Gordon Ltd	UK	Serfilco Ltd	US	Cougar Industries Ltd	UK
Godwin Pumps of America Inc	US	Seybert & Rahier GmbH	DE	Crane Process Flow Technologies Ltd	UK
Gorman-Rupp Company	US	SHURflo Ltd	UK	Crane Pumps & Systems	US
Gotec SA	CH	SHURflo Pump Manufacturing Co	US	Pompe Cucchi Srl	IT
GPM Pumps Inc	US	Sigma Group AS	CZ	DDA Srl	IT
Graco Inc	US	Simaco Elettromeccanica Srl	IT	Debem	IT
Grover Manufacturing Corporation	US	Michael Smith Engineers Ltd	UK	Defco	US
Hauke GmbH & Co KG	AT	SPX Process Equipment Ltd	UK	Delasco PCM GmbH	DE
Hüdig GmbH & Co KG	DE	Steinle Industripumpen GmbH	DE	Diaphragm Pumps Ltd	UK
Imovilli Pompe Srl	IT	Sunmotor International Ltd	CA	DKM	FR
Ingersoll-Rand/ARO	US	Swelore Engineering Pvt Ltd	IN	Dominator Aps	DK
Jabsco GmbH, ITT Industries	DE	Tapflo AB	SE	Feluwa Pumpen GmbH	DE
Jabsco UK, ITT Industries	UK	Thompson Pump & Manufacturing Co Inc	US	Flexachem Manufacturing Ltd	IE
Jabsco US, ITT Industries	US	Totton Pumps Ltd	UK	Flotronic Pumps Ltd	UK
Jaeco Fluid Sysytems Inc	US	Trebor	US	Flux-Geräte GmbH	DE
Johnson Pump (India), ATE Enterprises Ltd	IN	Tycon Alloy Industries (Hong Kong) Co Ltd	HK	Framo Engineering AS	NO
Johnson Pump AB	SE	Urac Pumpenfabrik GmbH & Co KG	DE	Gilbert Gilkes & Gordon Ltd	UK
Johnson Pump BV	NL	Varisco Srl	IT	Godwin Pumps of America Inc	US
Johnson Pumps of America Inc	US	Verder Group	NL	Gotec SA	CH
Kecol Pumps Ltd	UK	Versa-Matic Pump Company	US	Graco Inc	US
Kelair Pumps Australia Pty Ltd	AU	Victor Pumpen GmbH	DE	Grover Manufacturing Corporation	US
Kinder-Janes Engineers Ltd	UK	Wallace & Tiernan, Chemfeed Ltd	UK	Hauke GmbH & Co KG	AT
KNF Neuberger GmbH	DE	Wanner International Ltd	UK	Hüdig GmbH & Co KG	DE
Korina Pumps	GR	Warren Rupp Inc	US	Imovilli Pompe Srl	IT
Kovoplast Chlumec nad Cidlinou as	CZ	Wilden Pump & Engineering LLC	US		

Ingersoll-Rand/ARO	US	AxFlow AB	SE	Nikkiso Co Ltd	JP
Jaeco Fluid Sysytems Inc	US	AxFlow AS	NO	Nikkiso Pumps Europe GmbH	DE
JP Pumps Ltd	UK	AxFlow BeNeLux BV	NL	Omel Ltda	BR
Kelair Pumps Australia Pty Ltd	AU	AxFlow GmbH	AT	Pentair Inc	US
Kinder-Janes Engineers Ltd	UK	AxFlow GmbH	DE	Pentair Pumps SpA	IT
KNF Neuberger GmbH	DE	AxFlow GmbH	CH	Peroni Pompe SpA	IT
Korina Pumps	GR	Axflow Holding AB	SE	PreciDose Pumps & Systems	IN
Kovoplast Chlumec nad Cidlinou as	CZ	AxFlow Kft	HU	ProMinent Dosierttechnik GmbH	DE
Larius Srl	IT	AxFlow Ida	PL	ProMinent Fluid Controls UK Ltd	UK
LEWA GmbH	DE	AxFlow Ltd	IE	Pulsafeeder	US
Lutz (UK) Ltd	UK	AxFlow Ltd	UK	Pump & Package Ltd	UK
Lutz-Jesco	DE	AxFlow Oy	FI	Pump Engineering Co Pvt Ltd	IN
Lutz-Jesco America Corporation	US	AxFlow sro	CZ	Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA
Madden Manufacturing Inc	US	AxFlow SAS	FR	Roper Pump Company	US
Neptune Chemical Pump Company Inc	US	AxFlow SAS	ES	Roxspur Measurement & Control Ltd	UK
Omel Ltda	BR	AxFlow Sp Soo	PL	Saint-Gobain Performance Plastics	US
Plast-O-Matic Valves Inc	US	AxFlow SpA	IT	seepex GmbH & Co KG	DE
PreciDose Pumps & Systems	IN	Benxi Water Pump Factory	CN	seepex UK Ltd	UK
Price Pump Company	US	Beta Technology Inc	US	Seko Ltd	UK
Pulsafeeder	US	Bijur Lubricating Corporation	US	Seybert & Rahier GmbH	DE
Pump & Package Ltd	UK	Blue White Industries	US	SHURflo Ltd	UK
Pump Engineering Ltd	UK	Bühler Hochdrucktechnik GmbH	AT	SHURflo Pump Manufacturing Co	US
Pumper Parts LLC	US	Cakasa (Nigeria) Co Ltd	NG	Sigma Group AS	CZ
Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA	CAT Pumps	US	SPX Process Equipment Ltd	UK
Rietschle Thomas Schopfheim GmbH	DE	CAT Pumps (UK) Ltd	UK	Steinle Industripumpen GmbH	DE
Roxspur Measurement & Control Ltd	UK	Chempump	US	Swelore Engineering Pvt Ltd	IN
Saint-Gobain Performance Plastics	US	Cole-Parmer Instrument Company	US	Teledyne Isco Inc	US
Savino Barbera	IT	Debem	IT	Variopumps Pumpenbau GmbH	DE
Serfilco Europe Ltd	UK	Defco	US	Verder Group	NL
Serfilco Ltd	US	Delasco PCM GmbH	DE	Viking Pump Inc	US
Seybert & Rahier GmbH	DE	DKM	FR	Wallace & Tiernan, Chemfeed Ltd	UK
SHURflo Ltd	UK	EMS Pacific	US	Wanner International Ltd	UK
SHURflo Pump Manufacturing Co	US	Feluwu Pumpen GmbH	DE	Wilden Pump & Engineering LLC	US
Simaco Elettromeccanica Srl	IT	Flexachem Manufacturing Ltd	IE	Yamada America Inc	US
Michael Smith Engineers Ltd	UK	Fluid Metering Inc	US	Yamada Corporation	JP
Steinle Industripumpen GmbH	DE	Gotec SA	CH	Yamada Europe BV	NL
Swelore Engineering Pvt Ltd	IN	Graco Inc	US	Zenith Pumps Division, Parker Hannifin	US
Tapflo AB	SE	Grover Manufacturing Corporation	US	DIRECT-ACTING RECIPROCATING PUMPS — (includes pneumatic, hydraulic and steam actuation)	
Thompson Pump & Manufacturing Co Inc	US	Gysi Pumpen AG	CH		
Totton Pumps Ltd	UK	Haskel International Inc	US	ACD Cryo GmbH	DE
Trebor	US	Hauke GmbH & Co KG	AT	ACD Inc	US
Tyco - Southern Cross Plant	AU	Ingersoll-Rand/ARO	US	Acromet (Aust) Pty Ltd	AU
Tycon Alloy Industries (Hong Kong) Co Ltd	HK	Iwaki Co Ltd	JP	Air Pumping Engineering Service	UK
Varisco Srl	IT	Iwaki Europe GmbH	DE	Alfons de Backer & Co	BE
Verder Group	NL	Jaeco Fluid Sysytems Inc	US	Alltech Dosieranlagen GmbH	DE
Versa-Matic Pump Company	US	JLS International (UK) Ltd	UK	Annovireverberi SpA	IT
Victor Pumpen GmbH	DE	Kinder-Janes Engineers Ltd	UK	Asco Pompe srl	IT
Wallace & Tiernan, Chemfeed Ltd	UK	KNF Neuberger GmbH	DE	BBA Hranice sro	CZ
Wanner International Ltd	UK	LEWA GmbH	DE	Bühler Hochdrucktechnik GmbH	AT
Warren Rupp Inc	US	LMI Milton Roy	US	CAT Pumps	US
Wilden Pump & Engineering LLC	US	Lutz-Jesco	DE	CAT Pumps (UK) Ltd	UK
Yaltek AS	TR	Lutz-Jesco America Corporation	US	CDS-John Blue Company	US
Yamada America Inc	US	Madden Manufacturing Inc	US	Chempump	US
Yamada Corporation	JP	Mahr Metering Systems Corporation	US	Dawson Downie Lamont	UK
Yamada Europe BV	NL	Maximator GmbH	DE	Defco	US
METERING PUMPS — (flow with +/- 0.1% to +/- 3% with substantial dp changes)		Metalchem-Warszawa SA	PL	Delasco PCM GmbH	DE
		Milton Roy Europe	FR	DKM	FR
Ace Pump Corporation	US	Mono Pumps (Australia) Pty Ltd	AU	EMS Pacific	US
Air Pumping Engineering Service	UK	Mono Pumps (China) Ltd	CN	Flexachem Manufacturing Ltd	IE
Albany Engineering Company Ltd	UK	Mono Pumps (New Zealand) Ltd	NZ	Flojet Corporation	US
Aldos Ltd	UK	Mono Pumps Ltd	UK	Fluid Metering Inc	US
Aldos GmbH	DE	Monoflo Inc	US	Graco Inc	US
American Lewa Inc	US	Moyno Inc	US	Gzut SA Pumps Department	PL
Asco Pompe srl	IT	Neptune Chemical Pump Company Inc	US	Häny AG	CH
AxFlow A/S	DK	Netsch Mohnopumpen GmbH	DE		

Hauhinco	DE	Wright Pump	US	Alldos Ltd	UK
Hauke GmbH & Co KG	AT	Alldos GmbH	DE	Allweiler AG	DE
Heypac Ltd	UK			AxFlow A/S	DK
Horn GmbH & Co KG	DE	NON-METALLIC POSITIVE DISPLACEMENT PUMPS		AxFlow AB	SE
Ilung Precision Industry Company	KR	Alldos Ltd	UK	AxFlow AS	NO
Imovilli Pompe Srl	IT	AxFlow A/S	DK	AxFlow BeNeLux BV	NL
Iron Pump A/S	DK	AxFlow AB	SE	AxFlow GmbH	AT
Bombas Itur SA	ES	AxFlow AS	NO	AxFlow GmbH	DE
Jensen	US	AxFlow BeNeLux BV	NL	AxFlow GmbH	CH
Kamat Pumpen GmbH Co KG	DE	AxFlow GmbH	AT	Axflow Holding AB	SE
Kelair Pumps Australia Pty Ltd	AU	AxFlow GmbH	DE	AxFlow Kft	HU
Komline-Sanderson	US	AxFlow GmbH	CH	AxFlow Ida	PL
Kovoplast Chlumec nad Cidlinou as	CZ	Axflow Holding AB	SE	AxFlow Ltd	IE
Larius Srl	IT	AxFlow Kft	HU	AxFlow Ltd	UK
Liverani Srl	IT	AxFlow Ida	PL	AxFlow Oy	FI
Maximator GmbH	DE	AxFlow Ltd	IE	AxFlow sro	CZ
Metalchem-Warszawa SA	PL	AxFlow Ltd	UK	AxFlow SAS	FR
Motorrens SL	ES	AxFlow Oy	FI	AxFlow SAS	ES
FE Myers	US	AxFlow sro	CZ	AxFlow Sp Soo	PL
Nasosenergomash	UA	AxFlow SAS	FR	AxFlow SpA	IT
Nikkiso Co Ltd	JP	AxFlow SAS	ES	Caster HMD Kontro	UK
Nikkiso Pumps Europe GmbH	DE	AxFlow Sp Soo	PL	Lederle GmbH	DE
The Oilgear Company	US	AxFlow SpA	IT	MASO Process-Pumpen GmbH	DE
Omel Ltda	BR	Caster HMD Kontro	UK	Netzsch Mohnopumpen GmbH	DE
Pentair Inc	US	Equimavenca	VE	Nikkiso Co Ltd	JP
Pentair Pumps SpA	IT	Feluwa Pumpen GmbH	DE	Nikkiso Pumps Europe GmbH	DE
Peroni Pompe SpA	IT	Kelair Pumps Australia Pty Ltd	AU	Nova Magnetics Burgmann Ltd	CA
Plast-O-Matic Valves Inc	US	Kudu Industries Inc	CA	Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA
PreciDose Pumps & Systems	IN	MASO Process-Pumpen GmbH	DE	Rütschi Fluid AG	CH
Pump & Package Ltd	UK	PCM	FR	Seko Ltd	UK
Putzmeister Ltd	UK	PCM Asia Pacific	CN	SPX Process Equipment Ltd	UK
Ragazzini Srl	IT	PCM Delasco GmbH	DE	Sundyne Corporation	US
RMI Pressure Systems Ltd	UK	PCM Delasco Inc	US	Sundyne International SA	FR
Ruhrpumpen GmbH	DE	PCM Moineau Oilfield	CN	Verder Group	NL
Ruhrpumpen Inc	US	PCM Pompes Russia	RU	Vertiflo Pump Company	US
Saint-Gobain Performance Plastics	US	PCM Pompes Thailand	TH	Willy Vogel AG	DE
Seko Bono Exacta SpA	IT	PCM Pumps Ltd	UK	Warren Rupp Inc	US
Seko Ltd	UK	PCM Tunisia	TN		
Seybert & Rahier GmbH	DE	ProMinent Dosiertechnik GmbH	DE	HYDRAULIC MOTORS	
Sigma Group AS	CZ	ProMinent Fluid Controls UK Ltd	UK	Cross Manufacturing Inc	US
Sigmia Trading International	CZ	Rhine Ruhr Pumps & Valves (Pty) Ltd	ZA	Equimavenca	VE
Michael Smith Engineers Ltd	UK	Seko Ltd	UK	Kudu Industries Inc	CA
SPM Flow Control Inc	US	Sigma Group AS	CZ	PCM	FR
Steinle Industripumpen GmbH	DE	SPX Process Equipment Ltd	UK	PCM Asia Pacific	CN
Swelore Engineering Pvt Ltd	IN	Sundyne Corporation	US	PCM Delasco GmbH	DE
Taiko Kikai Industries Co Ltd	JP	Sundyne International SA	FR	PCM Delasco Inc	US
Teledyne Isco Inc	US	Verder Group	NL	PCM Moineau Oilfield	CN
Tuthill Corporation	US	Willy Vogel AG	DE	PCM Pompes Russia	RU
Wallace & Tiernan, Chemfeed Ltd	UK	Warren Rupp Inc	US	PCM Pompes Thailand	TH
Wanner International Ltd	UK			PCM Pumps Ltd	UK
Wheatley and Gaso Pump	US	SEALLESS POSITIVE DISPLACEMENT PUMPS		PCM Tunisia	TN
Woma Apparatebau GmbH	DE	Alldos GmbH	DE	Viking Pump Inc	US

18.5 Other pumps

Companies listed alphabetically by pump type

EJECTORS						
Allpumps Ltd	UK	Allpumps Ltd	UK	Gysi Pumpen AG	CH	
CAT Pumps	US	Argal Srl	IT	Horn GmbH & Co KG	DE	
CAT Pumps (UK) Ltd	UK	AxFlow A/S	DK	Hypro	US	
DAB Pumps SpA	IT	AxFlow AB	SE	Interpump Group SpA	IT	
DDA Srl	IT	AxFlow AS	NO	Kecol Pumps Ltd	UK	
Ebara Corporation	JP	AxFlow BeNeLux BV	NL	Korina Pumps	GR	
Finder Pompe SpA	IT	AxFlow GmbH	AT	Layne/Verti-Line	US	
Flojet Corporation	US	AxFlow GmbH	DE	Leszno Pump Factory	PL	
Graham Vacuum Pumps Ltd	UK	AxFlow GmbH	CH	Lutz (UK) Ltd	UK	
Grindex AB	SE	Axflow Holding AB	SE	Mather & Platt Pumps Ltd	IN	
Hüdig GmbH & Co KG	DE	AxFlow Kft	HU	Monarch Industries Ltd	CA	
ITT Flygt AB	SE	AxFlow Ida	PL	Netzsch Mohnopumpen GmbH	DE	
Körting Hannover AG	DE	AxFlow Ltd	IE	Pacer Pumps	US	
Matra SpA	IT	AxFlow Ltd	UK	Pomac Industries Group	NL	
Metalchem-Warszawa SA	PL	AxFlow Oy	FI	Pump Engineering Ltd	UK	
Metso Minerals (Sala) AB	SE	AxFlow sro	CZ	Rotomac Industries Pvt Ltd	IN	
FE Myers	US	AxFlow SAS	FR	Roxspur Measurement & Control Ltd	UK	
Rotex SA	GR	AxFlow SAS	ES	Ruhrpumpen GmbH	DE	
S & G Thermo fluids Ltd	UK	AxFlow Sp Soo	PL	Ruhrpumpen Inc	US	
Sharp Trendys	IN	AxFlow SpA	IT	Serfilco Europe Ltd	UK	
3S Systemtechnik AG	CH	Cakasa (Nigeria) Co Ltd	NG	Serfilco Ltd	US	
Pompe Vergani	IT	Catag AG	CH	Michael Smith Engineers Ltd	UK	
CH Warman Pump Group	ZA	Clasal	BE	Standard Pump Inc	US	
Waterman Industries Ltd	IN	Cougar Industries Ltd	UK	TKL	AU	
BARREL EMPTYING PUMPS — (powered and hand pumps)			Engineered Products Group Pty Ltd (EPG)	AU	Tyco - Southern Cross Plant	AU
Aker Kvaerner Eureka Pump Systems	NO	Fairbanks Morse Pump	US	Verder Group	NL	
Albany Engineering Company Ltd	UK	Finish Thompson Inc	US	HYDRAULIC-RAM PUMPS		
		Flux Pumps Corporation	US	PaPa Pumps Ltd	UK	
		Flux-Geräte GmbH	DE	SRS Crisafulli Inc	US	

18.6 Ancillary products and services

Companies listed alphabetically by product and/or service

ACCUMULATORS		Grundfos Pumps KK	JP	ITT Flygt AB	SE	
Kächele GmbH	DE	Grundfos Pumps Ltd	UK	Kudu Industries Inc	CA	
Pulseguard Ltd	UK	Grundfos Pumps Pty Ltd	AU	LMI Milton Roy	US	
RMI Pressure Systems Ltd	UK	Lowara SpA, ITT Industries	IT	PCM	FR	
Seko Ltd	UK	Mark Grundfos Ltda	BR	PCM Asia Pacific	CN	
ANTI-VIBRATION MOUNTINGS		Red Jacket, ITT Water Technology	US	PCM Delasco GmbH	DE	
Kächele GmbH	DE	Ture International Industrial Ltd	CN	PCM Delasco Inc	US	
BEARINGS		ELECTRIC MOTORS — VARIABLE SPEED			PCM Moineau Oilfield	CN
Junty Industries Ltd	CN	Brook Crompton	UK	PCM Pompes Russia	RU	
NSK Europe - European Bearings Business Unit	UK	Caprari SpA	IT	PCM Pompes Thailand	TH	
Nova Magnetics Burgmann Ltd	CA	Hamworthy Svanehøj A/S	DK	PCM Pumps Ltd	UK	
Saint-Gobain Ceramics	US	ELECTRIC MOTORS — VARIABLE FREQUENCY INVERTERS			PCM Tunisia	TN
Schaeffler (UK) Ltd	UK	Caprari SpA	IT	Robertson Technology Pty Ltd	AU	
SKF (UK) Ltd	UK	Goulds Pumps, ITT Water Technology	US	Schroedahl-Arrap, Speciality Valves	DE	
BYPASS/UNLOADER VALVES		Grundfos (Singapore) Pte Ltd	SG	Seko Ltd	UK	
Aldos GmbH	DE	Grundfos GmbH	DE	LIQUID LEVEL CONTROLLERS		
Aldos Ltd	UK	Grundfos Management A/S	DK	Aldos GmbH	DE	
RMI Pressure Systems Ltd	UK	Grundfos Management A/S	DK	Aldos Ltd	UK	
Schroedahl-Arrap, Speciality Valves	DE	Grundfos Pompe Italia Srl	IT	Allweiler AG	DE	
Seko Ltd	UK	Grundfos Pumpen Vertrieb GmbH	AT	Caprari SpA	IT	
CFD ANALYSIS		Grundfos Pumps Corporation	US	ITT Residential & Commercial Water	US	
Flowsolve Ltd	UK	Grundfos Pumps KK	JP	Marlow Pumps, ITT Water Technology	US	
PCA Engineers Ltd	UK	Grundfos Pumps Ltd	UK	Seko Ltd	UK	
CONCEPT VISULISATION		Grundfos Pumps Pty Ltd	AU	Warren Rupp Inc	US	
Jyoti Plastic Works Pvt Ltd	IN	Hamworthy Svanehøj A/S	DK	LUBRICATORS		
CONSULTANCY		Lowara SpA, ITT Industries	IT	Schaeffler (UK) Ltd	UK	
PCA Engineers Ltd	UK	Mark Grundfos Ltda	BR	POWER TRANSMISSION — SHAFT COUPLINGS-FLEXIBLE		
CONSULTANCY, TRAINING & TECHNICAL SUPPORT		Marlow Pumps, ITT Water Technology	US	KTR Corporation	US	
Pump Centre, ESR Technology Ltd	UK	Red Jacket, ITT Water Technology	US	KTR Couplings Ltd	UK	
DESIGN SOFTWARE		FILTERS — HIGH PRESSURE			KTR Kupplungstechnik GmbH	DE
PCA Engineers Ltd	UK	ITT Residential & Commercial Water	US	Prüftechnik Alignment Systems GmbH	DE	
EJECTORS AND INJECTORS		FILTERS — LIQUID			POWER TRANSMISSION — SHAFT COUPLINGS-RIGID	
Aldos GmbH	DE	Mefiag Division, Met-Pro Corporation	US	Caprari SpA	IT	
Aldos Ltd	UK	Seko Ltd	UK	KTR Corporation	US	
ITT Flygt AB	SE	Sethco Division, Met-Pro Corporation	US	KTR Couplings Ltd	UK	
Metso Minerals (Sala) AB	SE	FLOW METERS			KTR Kupplungstechnik GmbH	DE
Seko Ltd	UK	Alpeco Ltd	UK	Prüftechnik Alignment Systems GmbH	DE	
ELECTRIC MOTORS — POLE CHANGING		Flo-Dyne Ltd	UK	PULSATION DAMPERS		
Brook Crompton	UK	Liquid Controls	US	Aldos GmbH	DE	
Caprari SpA	IT	HOSE COUPLINGS AND FITTINGS			Aldos Ltd	UK
ELECTRIC MOTORS — SOFT STARTERS/ SOFT STOPS		Ture International Industrial Ltd	CN	Bredel Hose Pumps	NL	
Caprari SpA	IT	INSPECTION, INSURANCE AND CONSULTANCY			Flo-Dyne Ltd	UK
ELECTRIC MOTORS — STARTING EQUIPMENT		TriVista Engineering Ltd	UK	Flowguard Ltd	UK	
Caprari SpA	IT	INSTRUMENTATION			Liquid Controls	US
ELECTRIC MOTORS — SUBMERSIBLE		Aldos Ltd	UK	Pulseguard Ltd	UK	
Caprari SpA	IT	Blue White Industries	US	Saint-Gobain Performance Plastics	US	
Goulds Pumps, ITT Water Technology	US	Caprari SpA	IT	Seko Ltd	UK	
Grundfos (Singapore) Pte Ltd	SG	Milton Roy Europe	FR	Trebor	US	
Grundfos GmbH	DE	Prüftechnik Alignment Systems GmbH	DE	Uraca Pumpenfabrik GmbH & Co KG	DE	
Grundfos Management A/S	DK	Robertson Technology Pty Ltd	AU	Verder Group	NL	
Grundfos Management A/S	DK	Seko Ltd	UK	Warren Rupp Inc	US	
Grundfos Pompe Italia Srl	IT	Aldos GmbH	DE	Wheatley and Gaso Pump	US	
Grundfos Pumpen Vertrieb GmbH	AT	INSTRUMENTATION — PUMP PROTECTION			Yamada America Inc	US
Grundfos Pumps Corporation	US	Caprari SpA	IT	Yamada Corporation	JP	
		Equimavenca	VE	Yamada Europe BV	NL	
		Flowserve Corporation	US	PUMP BEARINGS - MECHANICAL CARBON		
		Hermetic-Pumpen GmbH	DE	Morgan AM & T	US	

PUMP BEARINGS - SILICON CARBIDE

Morgan AM & T US

PUMP INSTALLATION AND COMMISSIONING

ABS Deutschland GmbH DE

ABS Finland Oy FI

ABS France SAS FR

ABS Group SE

ABS Hellas SA GR

ABS Hidrobomba SA PL

ABS Hungary Trading HU

ABS Industria de Bombas Centrifugas Ltda BR

ABS International Srl IT

ABS Italy Srl IT

ABS Nopon Thai Co Ltd TH

ABS Oumoer A/S NO

ABS PolskaSp. Z.o.o. PL

ABS Pompalari Ltd TR

ABS Pompen BV NL

ABS Pumpen GmbH AT

ABS Pumps (Irl) Ltd IE

ABS Pumps AS EE

ABS Pumps Corporation CA

ABS Pumps Inc US

ABS Pumps Malaysia Sdn Bhd MY

ABS Pumps NV/SA BE

ABS Shanghai Co Ltd CN

ABS Shanghai Co Ltd Beijing Liaison Office CN

ABS Tecnologias del Agua SA ES

ABS Wastewater Technology (Pty) Ltd ZA

ABS Wastewater Technology Ltd UK

ABS Wastewater Technology Pte Ltd SG

AxFlow A/S DK

AxFlow AB SE

AxFlow AS NO

AxFlow BeNeLux BV NL

AxFlow GmbH AT

AxFlow GmbH DE

AxFlow GmbH CH

Axflow Holding AB SE

AxFlow Kft HU

AxFlow Ida PL

AxFlow Ltd IE

AxFlow Ltd UK

AxFlow Oy FI

AxFlow sro CZ

AxFlow SAS FR

AxFlow SAS ES

AxFlow Sp Soo PL

AxFlow SpA IT

Caprari SpA IT

Equimavenca VE

Flowserve Corporation US

Goulds Pumps, ITT Industrial & BioPharm Group US

Hermetic-Pumpen GmbH DE

Hidrostal Ltd UK

ITT Flygt AB SE

KSB Ltd UK

Kudu Industries Inc CA

Lederle GmbH DE

Lowara SpA, ITT Industries IT

Marlow Pumps, ITT Water Technology US

Mono Pumps (Australia) Pty Ltd AU

Mono Pumps (China) Ltd CN

Mono Pumps (New Zealand) Ltd NZ

Mono Pumps Ltd UK

Monoflo Inc US

PCM FR

PCM Asia Pacific CN

PCM Delasco GmbH DE

PCM Delasco Inc US

PCM Moineau Oilfield CN

PCM Pompes Russia RU

PCM Pompes Thailand TH

PCM Pumps Ltd UK

PCM Tunisia TN

Rotomac Industires Pvt Ltd IN

seepex GmbH & Co KG DE

seepex UK Ltd UK

Seko Ltd UK

SPP Pumps Ltd UK

Sterling Fluid Systems (Americas) Inc US

Sterling Fluid Systems (Austria) AT

Sterling Fluid Systems (Belgium) NV BE

Sterling Fluid Systems (France) SAS FR

Sterling Fluid Systems (Italy) SpA IT

Sterling Fluid Systems (Netherlands) NL

Sterling Fluid Systems (Schweiz) AG CH

Sterling Fluid Systems (UK) Ltd UK

Sterling SIHI GmbH DE

Sulzer Pumps CH

Teikoku Electric GmbH DE

Toyo Pumps Europe BE

Verder Group NL

Pumpenfabrik Ernst Vogel GmbH, ITT Industries AT

PUMP MAINTENANCE CONTRACTS

ABS Deutschland GmbH DE

ABS Finland Oy FI

ABS France SAS FR

ABS Group SE

ABS Hellas SA GR

ABS Hidrobomba SA PL

ABS Hungary Trading HU

ABS Industria de Bombas Centrifugas Ltda BR

ABS International Srl IT

ABS Italy Srl IT

ABS Nopon Thai Co Ltd TH

ABS Oumoer A/S NO

ABS PolskaSp. Z.o.o. PL

ABS Pompalari Ltd TR

ABS Pompen BV NL

ABS Pumpen GmbH AT

ABS Pumps (Irl) Ltd IE

ABS Pumps AS EE

ABS Pumps Corporation CA

ABS Pumps Inc US

ABS Pumps Malaysia Sdn Bhd MY

ABS Pumps NV/SA BE

ABS Shanghai Co Ltd CN

ABS Shanghai Co Ltd Beijing Liaison Office CN

ABS Tecnologias del Agua SA ES

ABS Wastewater Technology (Pty) Ltd ZA

ABS Wastewater Technology Ltd UK

ABS Wastewater Technology Pte Ltd SG

Aldos GmbH DE

Aldos Ltd UK

Allweiler AG DE

AxFlow A/S DK

AxFlow AB SE

AxFlow AS NO

AxFlow BeNeLux BV NL

AxFlow GmbH AT

AxFlow GmbH DE

AxFlow GmbH CH

Axflow Holding AB SE

AxFlow Kft HU

AxFlow Ida PL

AxFlow Ltd IE

AxFlow Ltd UK

AxFlow Oy FI

AxFlow sro CZ

AxFlow SAS FR

AxFlow SAS ES

AxFlow Sp Soo PL

AxFlow SpA IT

Equimavenca VE

Flowserve Corporation US

Goulds Pumps, ITT Industrial & BioPharm Group US

Grundfos (Singapore) Pte Ltd SG

Grundfos GmbH DE

Grundfos Management A/S DK

Grundfos Pompe Italia Srl IT

Grundfos Pumpen Vertrieb GmbH AT

Grundfos Pumps Corporation US

Grundfos Pumps KK JP

Grundfos Pumps Ltd UK

Grundfos Pumps Pty Ltd AU

Hermetic-Pumpen GmbH DE

Hidrostal Ltd UK

ITT Flygt AB SE

KSB Ltd UK

Kudu Industries Inc CA

Lowara SpA, ITT Industries IT

Mark Grundfos Ltda BR

Metso Minerals (Sala) AB SE

Milton Roy Europe FR

Mono Pumps (Australia) Pty Ltd AU

Mono Pumps (China) Ltd CN

Mono Pumps (New Zealand) Ltd NZ

Mono Pumps Ltd UK

Monoflo Inc US

Netzsch Mohnopumpen GmbH DE

PCM FR

PCM Asia Pacific CN

PCM Delasco GmbH DE

PCM Delasco Inc US

PCM Moineau Oilfield CN

PCM Pompes Russia RU

PCM Pompes Thailand TH

PCM Pumps Ltd UK

PCM Tunisia TN

RMI Pressure Systems Ltd UK

Robertson Technology Pty Ltd AU

Rotomac Industires Pvt Ltd IN

seepex GmbH & Co KG DE

seepex UK Ltd UK

Seko Ltd UK

SPP Pumps Ltd UK

Sterling Fluid Systems (Americas) Inc US

Sterling Fluid Systems (Austria) AT

Sterling Fluid Systems (Belgium) NV BE

Sterling Fluid Systems (France) SAS FR

Sterling Fluid Systems (Italy) SpA IT

Sterling Fluid Systems (Netherlands)	NL	Goulds Pumps,	US	ABS Industria de Bombas Centrifugas Ltda	BR
Sterling Fluid Systems (Schweiz) AG	CH	ITT Industrial & BioPharm Group		ABS International Srl	IT
Sterling Fluid Systems (UK) Ltd	UK	Grundfos (Singapore) Pte Ltd	SG	ABS Italy Srl	IT
Sterling SIHI GmbH	DE	Grundfos GmbH	DE	ABS Nopon Thai Co Ltd	TH
Sulzer Pumps	CH	Grundfos Management A/S	DK	ABS Oumoer A/S	NO
Teikoku Electric GmbH	DE	Grundfos Pompe Italia Srl	IT	ABS PolskaSp. Z.o.o.	PL
Toyo Pumps Europe	BE	Grundfos Pumpen Vertrieb GmbH	AT	ABS Pompalari Ltd	TR
Uraca Pumpenfabrik GmbH & Co KG	DE	Grundfos Pumps Corporation	US	ABS Pompen BV	NL
Verder Group	NL	Grundfos Pumps KK	JP	ABS Pumpen GmbH	AT
Pumpenfabrik Ernst Vogel GmbH,	AT	Grundfos Pumps Ltd	UK	ABS Pumps (Irl) Ltd	IE
ITT Industries		Grundfos Pumps Pty Ltd	AU	ABS Pumps AS	EE
PUMP REPAIR		Hermetic-Pumpen GmbH	DE	ABS Pumps Corporation	CA
ABS Deutschland GmbH	DE	Hidrostal Ltd	UK	ABS Pumps Inc	US
ABS Finland Oy	FI	ITT Flygt AB	SE	ABS Pumps Malaysia Sdn Bhd	MY
ABS France SAS	FR	KSB Ltd	UK	ABS Pumps NV/SA	BE
ABS Group	SE	Kudu Industries Inc	CA	ABS Shanghai Co Ltd	CN
ABS Hellas SA	GR	Lederle GmbH	DE	ABS Shanghai Co Ltd Beijing Liaison Office	CN
ABS Hidrobomba SA	PL	Lowara SpA, ITT Industries	IT	ABS Tecnologias del Agua SA	ES
ABS Hungary Trading	HU	Mark Grundfos Ltda	BR	ABS Wastewater Technology (Pty) Ltd	ZA
ABS Industria de Bombas Centrifugas Ltda	BR	Marlow Pumps, ITT Water Technology	US	ABS Wastewater Technology Ltd	UK
ABS International Srl	IT	Mono Pumps (Australia) Pty Ltd	AU	ABS Wastewater Technology Pte Ltd	SG
ABS Italy Srl	IT	Mono Pumps (China) Ltd	CN	Allweiler AG	DE
ABS Nopon Thai Co Ltd	TH	Mono Pumps (New Zealand) Ltd	NZ	AxFlow A/S	DK
ABS Oumoer A/S	NO	Mono Pumps Ltd	UK	AxFlow AB	SE
ABS PolskaSp. Z.o.o.	PL	Monoflo Inc	US	AxFlow AS	NO
ABS Pompalari Ltd	TR	Netzsch Mohnopumpen GmbH	DE	AxFlow BeNeLux BV	NL
ABS Pompen BV	NL	PCM	FR	AxFlow GmbH	AT
ABS Pumpen GmbH	AT	PCM Asia Pacific	CN	AxFlow GmbH	DE
ABS Pumps (Irl) Ltd	IE	PCM Delasco GmbH	DE	AxFlow GmbH	CH
ABS Pumps AS	EE	PCM Delasco Inc	US	Axflow Holding AB	SE
ABS Pumps Corporation	CA	PCM Moineau Oilfield	CN	AxFlow Kft	HU
ABS Pumps Inc	US	PCM Pompes Russia	RU	AxFlow Ida	PL
ABS Pumps Malaysia Sdn Bhd	MY	PCM Pompes Thailand	TH	AxFlow Ltd	IE
ABS Pumps NV/SA	BE	PCM Pumps Ltd	UK	AxFlow Ltd	UK
ABS Shanghai Co Ltd	CN	PCM Tunisia	TN	AxFlow Oy	FI
ABS Shanghai Co Ltd Beijing Liaison Office	CN	RMI Pressure Systems Ltd	UK	AxFlow sro	CZ
ABS Tecnologias del Agua SA	ES	Rotomac Industires Pvt Ltd	IN	AxFlow SAS	FR
ABS Wastewater Technology (Pty) Ltd	ZA	seepex GmbH & Co KG	DE	AxFlow SAS	ES
ABS Wastewater Technology Ltd	UK	seepex UK Ltd	UK	AxFlow Sp Soo	PL
ABS Wastewater Technology Pte Ltd	SG	Seko Ltd	UK	AxFlow SpA	IT
Allidos GmbH	DE	SPP Pumps Ltd	UK	Caprari SpA	IT
Allidos Ltd	UK	Sterling Fluid Systems (Americas) Inc	US	Equimavenca	VE
Allweiler AG	DE	Sterling Fluid Systems (Austria)	AT	Flowserve Corporation	US
AxFlow A/S	DK	Sterling Fluid Systems (Belgium) NV	BE	Goulds Pumps,	US
AxFlow AB	SE	Sterling Fluid Systems (France) SAS	FR	ITT Industrial & BioPharm Group	
AxFlow AS	NO	Sterling Fluid Systems (Italy) SpA	IT	Goulds Pumps, ITT Water Technology	US
AxFlow BeNeLux BV	NL	Sterling Fluid Systems (Netherlands)	NL	Hermetic-Pumpen GmbH	DE
AxFlow GmbH	AT	Sterling Fluid Systems (Schweiz) AG	CH	Hidrostal Ltd	UK
AxFlow GmbH	DE	Sterling Fluid Systems (UK) Ltd	UK	ITT Flygt AB	SE
AxFlow GmbH	CH	Sterling SIHI GmbH	DE	ITT Residential & Commercial Water	US
Axflow Holding AB	SE	Sulzer Pumps	CH	Kudu Industries Inc	CA
AxFlow Kft	HU	Teikoku Electric GmbH	DE	Lowara SpA, ITT Industries	IT
AxFlow Ida	PL	Toyo Pumps Europe	BE	Marlow Pumps, ITT Water Technology	US
AxFlow Ltd	IE	Uraca Pumpenfabrik GmbH & Co KG	DE	Metso Minerals (Sala) AB	SE
AxFlow Ltd	UK	Verder Group	NL	PCM	FR
AxFlow Oy	FI	Pumpenfabrik Ernst Vogel GmbH,	AT	PCM Asia Pacific	CN
AxFlow sro	CZ	ITT Industries		PCM Delasco GmbH	DE
AxFlow SAS	FR	PUMP SELECTION SOFTWARE		PCM Delasco Inc	US
AxFlow SAS	ES	ABS Deutschland GmbH	DE	PCM Moineau Oilfield	CN
AxFlow Sp Soo	PL	ABS Finland Oy	FI	PCM Pompes Russia	RU
AxFlow SpA	IT	ABS France SAS	FR	PCM Pompes Thailand	TH
Dawson Downie Lamont	UK	ABS Group	SE	PCM Pumps Ltd	UK
Equimavenca	VE	ABS Hellas SA	GR	PCM Tunisia	TN
Flowserve Corporation	US	ABS Hidrobomba SA	PL	seepex GmbH & Co KG	DE
		ABS Hungary Trading	HU	seepex UK Ltd	UK

Pumpenfabrik Ernst Vogel GmbH, ITT Industries	AT	Mono Pumps (New Zealand) Ltd	NZ	SEAL FACE COMPONENTS — SILICON CARBIDE	
		Mono Pumps Ltd	UK		
PUMP UPGRADES		Monoflo Inc	US	Morgan AM & T	US
ABS Deutschland GmbH	DE	Moyno Inc	US	SEALING RINGS	
ABS Finland Oy	FI	Netzsch Mohnopumpen GmbH	DE	Junty Industries Ltd	CN
ABS France SAS	FR	PCM	FR	Leak-Proof Engineering (I) Pvt Ltd.	IN
ABS Group	SE	PCM Asia Pacific	CN	Morgan AM & T	US
ABS Hellas SA	GR	PCM Delasco GmbH	DE	Saint-Gobain Ceramics	US
ABS Hidrobomba SA	PL	PCM Delasco Inc	US		
ABS Hungary Trading	HU	PCM Moineau Oilfield	CN	SEALS — BELLOWS	
ABS Industria de Bombas Centrifugas Ltda	BR	PCM Pompes Russia	RU	Burgmann Industries GmbH & Co KG	DE
ABS International Srl	IT	PCM Pompes Thailand	TH	Flowserve Corporation	US
ABS Italy Srl	IT	PCM Pumps Ltd	UK	Junty Industries Ltd	CN
ABS Nopon Thai Co Ltd	TH	PCM Tunisia	TN	Morgan AM & T	US
ABS Oumoer A/S	NO	Seko Ltd	UK	SEALS — MAGNETIC COUPLING	
ABS PolskaSp. Z.o.o.	PL	Sethco Division, Met-Pro Corporation	US	Nova Magnetics Burgmann Ltd	CA
ABS Pompalari Ltd	TR	SPP Pumps Ltd	UK		
ABS Pompen BV	NL	Sterling Fluid Systems (Americas) Inc	US	SEALS — MECHANICAL	
ABS Pumpen GmbH	AT	Sterling Fluid Systems (Austria)	AT	Burgmann Industries GmbH & Co KG	DE
ABS Pumps (Iri) Ltd	IE	Sterling Fluid Systems (Belgium) NV	BE	John Crane UK Ltd	UK
ABS Pumps AS	EE	Sterling Fluid Systems (France) SAS	FR	Equimavenca	VE
ABS Pumps Corporation	CA	Sterling Fluid Systems (Italy) SpA	IT	Flowserve Corporation	US
ABS Pumps Inc	US	Sterling Fluid Systems (Netherlands)	NL	Goulds Pumps,	US
ABS Pumps Malaysia Sdn Bhd	MY	Sterling Fluid Systems (Schweiz) AG	CH	ITT Industrial & BioPharm Group	
ABS Pumps NV/SA	BE	Sterling Fluid Systems (UK) Ltd	UK	ITT Flygt AB	SE
ABS Shanghai Co Ltd	CN	Sterling SIHI GmbH	DE	ITT Residential & Commercial Water	US
ABS Shanghai Co Ltd Beijing Liaison Office	CN	Sulzer Pumps	CH	Junty Industries Ltd	CN
ABS Technologias del Agua SA	ES	Toyo Pumps Europe	BE	Kudu Industries Inc	CA
ABS Wastewater Technology (Pty) Ltd	ZA	Uraca Pumpenfabrik GmbH & Co KG	DE	Leak-Proof Engineering (I) Pvt Ltd.	IN
ABS Wastewater Technology Ltd	UK	Pumpenfabrik Ernst Vogel GmbH, ITT Industries	AT	Metso Minerals (Sala) AB	SE
ABS Wastewater Technology Pte Ltd	SG			Morgan AM & T	US
Allweiler AG	DE	RELIEF VALVES		PCM	FR
Dawson Downie Lamont	UK	Allidos GmbH	DE	PCM Asia Pacific	CN
Dean Pump Division, Met-Pro Corporation	US	Allidos Ltd	UK	PCM Delasco GmbH	DE
Equimavenca	VE	Caprari SpA	IT	PCM Delasco Inc	US
Flowserve Corporation	US	ITT Residential & Commercial Water	US	PCM Moineau Oilfield	CN
Goulds Pumps,	US	Netzsch Mohnopumpen GmbH	DE	PCM Pompes Russia	RU
ITT Industrial & BioPharm Group		Plast-O-Matic Valves Inc	US	PCM Pompes Thailand	TH
Hermetic-Pumpen GmbH	DE	Rotomac Industries Pvt Ltd	IN	PCM Pumps Ltd	UK
Hidrostal Ltd	UK	Seko Ltd	UK	PCM Tunisia	TN
ITT Flygt AB	SE	REVERSE ENGINEERING		Saint-Gobain Ceramics	US
ITT Residential & Commercial Water	US	Jyoti Plastic Works Pvt Ltd	IN	SEALS — OIL	
Kudu Industries Inc	CA	ROTORS AND VANES — MECHANICAL CARBON		Burgmann Industries GmbH & Co KG	DE
Lowara SpA, ITT Industries	IT	Morgan AM & T	US	Flowserve Corporation	US
Marlow Pumps, ITT Water Technology	US			Morgan AM & T	US
Mefiag Division, Met-Pro Corporation	US	SEAL FACE COMPONENTS — MECHANICAL CARBON		3D MODELLING (for plastic products)	
Mono Pumps (Australia) Pty Ltd	AU	Morgan AM & T	US	Jyoti Plastic Works Pvt Ltd	IN
Mono Pumps (China) Ltd	CN				

18.7 Trade Names

Companies listed alphabetically by Trade Name or Product Name

10 Series <i>Sel-priming centrifugal chemical handling pumps</i> Gorman-Rupp Company	US	Boostermatic <i>Water pressure/flow booster pumps</i> Stuart Turner Ltd	UK	Flojet <i>Diaphragm pumps, industrial and beverage</i> Jabsco UK, ITT	UK
ABS <i>Global solution provider in wastewater technology</i> ABS Group	SE	Caster <i>Sealless pumps</i> Caster HMD Kontro	UK	Fybroc <i>Corrosion resistant, fibreglass reinforced plastic pumps</i> Fybroc Division, Met-Pro Corporation	US
A-C Fire Pump <i>Fire pump range</i> ITT Residential & Commercial Water	US	Centri Pro <i>Accessories, motors and control boxes</i> Goulds Pumps, ITT Water Technology	US	Goulds <i>Pump range</i> ITT Residential & Commercial Water	US
All Heat <i>Pumps for heat transfer</i> Allweiler AG	DE	Contra <i>End suction centrifugal pumps</i> Hilge Pumps Ltd	UK	Grundfos <i>Pump range</i> Grundfos	DK
All Marine <i>Pumps for ships and offshore</i> Allweiler AG	DE	CPD <i>Centrifugal pump design</i> PCA Engineers Ltd	UK	Hazleton <i>Slurry pumps</i> Weir Minerals Division	US
All Power <i>Pumps for power generation plants</i> Allweiler AG	DE	Dawson & Downie <i>Reciprocating pumps</i> Dawson Downie Lamont	UK	Hexoloy® <i>Sintered silicon carbide</i> Saint-Gobain Ceramics	US
Amarex <i>Submersible motor pumps</i> KSB Ltd	UK	Dean Pump <i>Industrial process pumps for high temperature liquids</i> Dean Pump Division, Met-Pro Corporation	US	High efficient magnetic coupling <i>Seals, pump, mixers, compressors</i> Nova Magnetics Burgmann Ltd	CA
Amrut <i>Submersible pumps</i> Amrit Engineering Pvt Ltd	IN	Delasco <i>Peristaltic pumps</i> PCM	FR	HMD Kontro <i>Sealless magnetic drive pumps</i> Caster HMD Kontro	UK
Ansimag <i>Magnetically driven non-metallic centrifugal pumps</i> Ansimag Inc	US	Dosys <i>Dosing, injection, inline, mixing, coating and filling systems</i> PCM	FR	Holden and Brooke <i>Positive displacement plunger pumps</i> RMI Pressure Systems Ltd	UK
Apollo <i>Pumps and pumping stations</i> Apollo Gössnitz GmbH	DE	Dry Guard <i>Magnetic drive pump bearings</i> Goulds Pumps, ITT Industrial & BioPharm Group	US	Hydovar <i>Frequency controller</i> Pumpenfabrik Ernst Vogel GmbH, ITT Industries	A
Armourface <i>Wear resistant technology</i> Midland Pump Manufacturing Co Ltd	UK	Duo <i>Vacuum prime pumps</i> Varisco Srl	IT	Hydro Servant <i>Variable speed controllers</i> Red Jacket, ITT Water Technology	US
Armstrong Pumps <i>Centrifugal pump range</i> RMI Pressure Systems Ltd	UK	Durco <i>Pump range</i> Flowserve Corporation	US	Hydrovac <i>Variable speed drive</i> Lowara SpA, ITT Industries	I
Autoclude <i>Peristaltic pump range</i> Autoclude Pumps	NL	Enduro <i>4" submersible pumps</i> Red Jacket, ITT Water Technology	US	IC <i>ISO process pumps</i> Goulds Pumps, ITT Industrial & BioPharm Group	US
Autoprene <i>Extruded thermal plastic pump tubes</i> Autoclude Pumps	NL	Etron Profi <i>Electronic variable speed controllers</i> Alldos Ltd	UK	IDP <i>Pump range</i> Flowserve Corporation	US
Balanced Flow <i>Variable speed pump controllers</i> Goulds Pumps, ITT Water Technology	US	Even Wall® <i>Constant rubber thickness for increased performance of PC pumps</i> Kaechele GmbH	DE	INA <i>Rolling bearing and linear motion technology</i> Schaeffler (UK) Ltd	DE
Bell & Gossett <i>Pump range</i> ITT Residential & Commercial Water	US	FAG <i>Rolling bearing and linear motion technology</i> Schaeffler (UK) Ltd	UK	INA <i>Bearings</i> Schaeffler (UK) Ltd	UK
Bibo <i>Slim line submersible pumps</i> ITT Flygt AB	SE	Flexorber <i>PTFE diaphragm pulsation preventer</i> Pulseguard Ltd	UK	Jabsco <i>Flexible impeller, sliding vane and rotary lobe pumps</i> Jabsco UK, ITT	UK

Jet Power UHP pump units, UHP water jetting systems Uraca Pumpenfabrik GmbH & Co KG	DE	Noralide® Hot pressed silicon nitride Saint-Gobain Ceramics	US	Rotamix Digester jet mixing systems Vaughan Company Inc	US
Jonio Self-priming centrifugal pumps Varisco Srl	IT	NOVAlobe Rotary lobe pumps Hilge Pumps Ltd	UK	Rotex Elastic, flexible coupling, also spacer coupling KTR Kupplungstechnik GmbH	DE
Junty For mechanical seals and other pump parts Junty Industries Ltd	CN	OK Multistage barrel pumps (BBS) Weir Pumps Ltd	UK	Roto-Jet® Pitot tube pumps Weir Specialty Pumps	US
Keebush Thermosetting plastic GRP/Furane resin Kestner Engineering Co Ltd	UK	Orion Horizontal rubber and metal lined pumps Metso Minerals (Sala) AB	SE	Rotomac Progressive cavity pumps Rotomac Industries Pvt. Ltd	IN
Keeplus Compression moulded GRP vinyl ester/polyester material Kestner Engineering Co Ltd	UK	Pegson pumps Marine engine, water cooling pumps Terex Powertrain Ltd	UK	Rule Marine submersible pumps Jabsco UK, ITT	UK
LaBour Liquid centrifugal pumps Sterling Fluid Systems Group	US	PetroProof Hose pumps for hydrocarbon liquids Bredel Hose Pumps	NL	Sala Vertical rubber and metal lined pumps Metso Minerals (Sala) AB	SE
Layne & Bowler Centrifugal vertical, mixed flow, and propeller pumps Layne/Verti-Line	US	Pipehugger Liquid in bladder pulsation preventer Pulseguard Ltd	UK	Sandpiper Air-operated double diaphragm pumps Warren Rupp Inc	US
LFP Low flow pumps - down to 0.16 cc/rev Midland Pump Manufacturing Co Ltd	UK	Poly-Norm Elastic, flexible couplings, short DBSE, also spacer couplings KTR Kupplungstechnik GmbH	DE	Scumbuster Digester scum mixing pumps Vaughan Company Inc	US
Magnochem Magnetic Drive pumps KSB Ltd	UK	Primeline Self-priming centrifugal pumps Marlow Pumps, ITT Water Technology	US	seepex Progressive cavity pumps for low to highly-viscous, aggressive and abrasive media seepex GmbH & Co KG	DE
Mak 66 magnetic couplings Seals, pump, mixers, compressors Nova Magnetix Burgmann Ltd	CA	Primeroyal High flow and high pressure Milton Roy Europe	FR	Seko Dosing pumps, controllers and accessories Seko Ltd	UK
Marathon Air-operated double diaphragm pumps Warren Rupp Inc	US	Primus Dosing pumps Alldos Ltd	UK	Seoca Water pumps Ture International Industrial Ltd	CN
Mefiag Pumps and filter systems Mefiag Division, Met-Pro Corporation	US	Pump Drive Variable speed drives for pumps KSB Ltd	UK	Series G Dosing pumps with mechanically-actuated diaphragms Milton Roy Europe	FR
Mighty-Lite Gas engine-driven self-priming centrifugal pumps Marlow Pumps, ITT Water Technology	US	Pumpguard In line true flow thru pulsation preventer Pulseguard Ltd	UK	Sethco Corrosion resistant pumps and filter systems Sethco Division, Met-Pro Corporation	US
MIP Reg Maintenance In Place design reduces life cycle costs and downtime Börger GmbH	DE	Purebide™ Silicon carbide Morgan AM & T	US	Showermate Plastic shower pumps Stuart Turner Ltd	UK
Moineau Progressing cavity pumps PCM	FR	Purebon Mechanical carbon Morgan AM & T	US	SIHI Liquid centrifugal pumps Sterling Fluid Systems Group	US
Monbloc® Compact progressing cavity pumps Mono Pumps Ltd	UK	R & M Progressive cavity pumps Moyno Inc	US	SIPLA Self-priming centrifugal pumps Hilge Pumps Ltd	UK
Monsoon Brass shower/household pressure boosting pumps Stuart Turner Ltd	UK	Radex-N Flexible disc couplings KTR Kupplungstechnik GmbH	DE	Spandau Coolant pumps for machine tools Willy Vogel AG	DE
Moyno® Progressive cavity pumps Moyno Inc	US	Ramoy Progressive cavity pumps Moyno Inc	US	Spray 'N Ject Pump proofing/injection/portable pumps Midland Pump Manufacturing Co Ltd	UK
Murrator® Packaged pumping systems Mono Pumps Ltd	UK	Ready Small modern drainage pumps ITT Flygt AB	SE	SPX Series Heavy duty hose pumps Bredel Hose Pumps	NL
		Repower Mining International Long wall mining pumps RMI Pressure Systems Ltd	UK		

Super T Series <i>Self-priming centrifugal trash pumps</i> Gorman-Rupp Company	US	TrueDos® <i>Digital dosing pumps</i> Alldos Ltd	UK	Verderair <i>Double diaphragm pumps</i> Verder Group	NL
Tantiron <i>15% high silicon iron alloy</i> Kestner Engineering Co Ltd	UK	Tsurumi <i>Pump range</i> Tsurumi Manufacturing Co Ltd	JP	Verderflex <i>Hose and tube pumps</i> Verder Group	NL
Tecnum <i>Centrifugal pumps</i> Casals Cardona Industries SA	ES	TWK <i>Tank cleaning heads</i> Urac Pumpenfabrik GmbH & Co KG	DE	Verdermag <i>Magnetic drive centrifugal pumps</i> Verder Group	NL
Terex Pumps <i>Mobile, diesel driven self-priming pump sets</i> Terex Powertrain Ltd	UK	TWL <i>Two stage integral steam turbine pumps</i> Weir Pumps Ltd	UK	Vibrastop® <i>Engineered rubber parts acting as vibration decoupler</i> Kächele GmbH	DE
Thom Lamont <i>Reciprocating pumps</i> Dawson Downie Lamont	UK	Tycon Alloy Industries <i>Pump range</i> Tycon Alloy Industries (Hong Kong) Co Ltd	HK	Vista <i>Visual turbomachinery analysis</i> PCA Engineers Ltd	UK
Thomas <i>Horizontal heavy duty pumps</i> Metso Minerals (Sala) AB	SE	Type 260 <i>Seals, pumps, mixers, compressors</i> Nova Magnetics Burgmann Ltd	CA	Vogel-Pumpen <i>Pump range</i> Pumpenfabrik Ernst Vogel GmbH, ITT Industries	A
Toyo <i>Submersible pumps with agitator</i> Toyo Pumps Europe	BE	Ultra V Series <i>High performance self-priming centrifugal trash pumps</i> Gorman-Rupp Company	US	Wemco® <i>Self-priming pumps</i> Weir Specialty Pumps	US
Tranquilizers <i>Pulsation dampers</i> Warren Rupp Inc	US	Uniglide <i>Single stage axially split casing pumps</i> Weir Pumps Ltd	UK	Wemco®-Hidrosta® <i>Screw impeller pumps</i> Weir Specialty Pumps	US
Trash Hog 2 <i>Self-priming solids handling centrifugal pumps</i> Marlow Pumps, ITT Water Technology	US	Urac <i>High pressure pumps</i> Urac Pumpenfabrik GmbH & Co KG	DE	Worthington <i>Pump range</i> Flowserve Corporation	US
Trimax <i>Positive displacement plunger pumps</i> RMI Pressure Systems Ltd	UK	Vaughan <i>Chopper pumps</i> Vaughan Company Inc	US	Yanquan <i>Split casing single stage double suction centrifugal pumps</i> Tangshan Pump Factory	CN

Index

1% CrMo	43	Alkyd	213	API 610	8, 9, 17, 20, 22, 248, 339, 361
11-13% Cr steel	18, 20, 66, 208	Allowable leakage	3	API 611	276
12Cr steel	232	Allowable noise level	3	API 671	248
15-5PH	43	Alloy steel	7	API 674	148, 339
18-10-2 stainless steel	7, 20	Alloyed cast iron	206	API 675	339
18-8 stainless steel	7	Alumina	215	API 676	148, 339
22Cr 13Ni 5Mo	43	Aluminium	45, 204	API 682	8, 10, 238
25Cr 5Ni 2Mo	10	Aluminium alloys	210	Aragonite	334
304 and 316 stainless steel	293	Aluminium bronze	67	Archimedes screw pumps	33
3-phase squirrel-cage motors	264, 271	Aluminium oxide	215	Area	391
3-phase supply	262	Alundum	334	Asbestos	215, 232
5-rotor screw pumps	49	American Bureau of Shipping	380	Aseptic pumping	37
A		American Gear Manufacturers Association (AGMA)	282	ASME	381
Abrasive liquids	220	American Institute of Chemical Engineers (AIChE)	94	ASME B15.1	258
Abrasive solids	334	American National Standards Institute (ANSI)	94	ASME VIII	204
Abrasiveness	23	American Petroleum Institute (API)	62, 94	ASME/ANSI B73.1	7, 29
Absolute viscosity	57	American Society of Mechanical Engineers (ASME)	62, 94	ASME/ANSI B73.2	11
AC motors	264	Amino	213	ASME/ANSI Standards	8
AC slip ring motors	191	Ammeter	274	Assembly	294
AC squirrel-cage motors	191, 250	Ancillary equipment	280, 338	ASTM	381
Acceleration head	152	Accumulators	286	ASTM A278	205
Acceleration Head Loss	149	Belt drives	281	ATEX Regulations	3, 266, 278
Acceptance testing	386	Gearboxes	281	Attachment	252
Accumulators	5, 181, 178, 324, 365, 373	Instrumentation	289	Austenitic stainless steels	208, 293
Acetal	45, 48	Introduction	280	Automatic non-return valves	285
ACGHI	63	Mountings	280	Automatic water supply packages	5
Acoustic dampers	288	Non-return valves	283	Auxiliary pumps	229
Acoustic velocity	59	Pulsation dampers	286	Axial flow pumps	26, 149
ADR	381	Relief valves	282	Axial misalignment	249
Affinity Laws	131, 192, 193, 346, 375	Useful references	290	Axial piston pumps	40
Agricultural industry	33	Angular acceleration	391	Axial propeller pumps	332
Agricultural machinery	40	Angular misalignment	249, 250, 255	Axial pumps	136
Agrifoodstuffs	27, 386	Angular velocity	391	Axial thrust	132
Air motors	190, 197	Animal oils	68	Axial thrust balancing	377
Air vessels	102	Annual energy costs	321	Axially-split pumps	19, 20
Air-assisted valve	283	Annuity method	320, 327	B	
Aircraft fuel systems	75	Annunciators	289, 311	Back pressure	282
Air-driven pumps	47	ANSI	381	Back-pull-out	6
Air-hydro	47	ANSI B31.3	62	Back-to-back double seal	237
Air-lift pumps	52	ANSI B73.1	28, 381	Balance disc	20
Air-operated double-diaphragm pumps	16, 17, 45, 48	ANSI HI 5.1-5.6	29	Ball bearings	17, 20, 361
AISI	208	ANSI/AGMA 2001	282	Ball valves for solids	42
AISI 316	67	ANSI/API 612	276	Ballast pumping	13
Alignment		ANSI/HI 1.1-1.6	153	Bar	388
Alignment measurement and procedure	252, 254	API 500	270	Barrel pumps	3, 22
				Barrel-emptying pumps (powered and hand pumps)	51

Barrier condensate cycle	377	Burst-proof diaphragm coupling	258	Chemical composition	293
Barrier liquid	230, 241	Butterfly check valves	284	Chemical dosing	200
Baseplate and alignment	304	By-pass regulation	177	Chemical Industries Association (CIA)	94
Baseplates	252, 280, 294	Bypass valves	365	Chemical industry	349
Bauxite	334	C		Chemical processing	43, 182, 330
Bearing bracket	3	Calcium carbonate	334	Chemical pulps	106
Bearing bracket pumps	344	Calorimetric flow meters	120	Chevron sets	243
Bearing brackets	3, 6, 10, 344	Candy production	370	Chlor-alkali manufacturing	349
Bearing housing	17	Canned motor pumps	359	Chlor-alkali electrolysis	349
Bearing pedestal	3	Canned motor rotodynamic pumps	28, 228	Chlorination	46
Bearing performance	10	Canned motors	49	Chlorine	349
Bearing seizure	273	Car washes	43	Chloroprene	48
Bearings	276, 314	Carbide precipitation	208	Chrome	204
Belt drives	281	Carbon	215	Chrome iron	40
Belts	188	Carbon bearings	343	Chromium	206
Bends	308	Carbon dioxide (CO ₂) in water	66	Circuit breakers	265
Bernoulli's equation	96	Carbon dioxide injection	43	Circular gaskets	18
Best Efficiency Point (BEP)	131, 146	Carbon dioxide supercritical extraction	366	Circulating pump packages	289
Bilge pumps	13, 14	Carbon steels	7, 18, 20, 34, 293	Circulation pumps	351, 352
Biotechnology	386	Carbonate equilibrium	65	Circumferential piston pumps	36, 37
Biotechnology industry	27	Carbonic acid	65	Clamping sleeves	252
Blue asbestos	232	Cardan	35	Clarification of specifications	296
Boiler	350	Cardan joints	344	Classification of other pump types	145
Boiler feed pumps	3, 19, 43, 74, 200, 362, 374	Care of equipment	312	Classification of positive displacement pumps	145
Boiling point	56	Cargo pumps	13	Classification of rotodynamic pumps by application	138
Bolts	304	Carpenter 20	7	Classification societies	380
Booster pumps	4, 182, 374	Cartridge seals	237	Clay	334
Booster station	351	Casing efficiency	128	Clean liquid applications	10
Borehole pumps	20	Cast iron	7, 18, 32, 38, 40, 43, 45, 66	Clean water	15
Boreholes	26, 267	Cast steel	40	Cleaning	41
Boyle's Law	180	Castings	208	Cleaning In Place (CIP)	27
Brackish water	66	Caustic soda	349	Close coupled magnetically driven pumps	28
Branched pipework systems	158, 164	Cavitation	37, 40, 43, 50, 64, 67, 107, 127, 145, 147-148, 165, 169-170, 218, 221, 364, 372, 375	Cloud point	68
Brass	210	Cavitation testing	376	Coal	334
Bronze	18, 43, 64	Cellulose	74	Coal mining	40
BS 1042	122	Cellulose industry	37	Coatings	215
BS 1452	205	CEN	380, 381	Colebrook-White equation	100
BS 2869	94	CENELEC	94, 269, 381	Colmonox	215
BS 3092	248, 258	Central heating circulators	10, 268	Commissioning	310, 313
BS 3170	248	Central heating systems	5, 350	Compact centrifugal pump systems	360
BS 3680	123	Centre height	269	Compact pumps	6
BS 3766	6	Centrifugal pump impeller	177	Component efficiency	327
BS 4231	69, 94	Centrifugal pumps	135, 173, 193, 258, 286, 316, 326, 331, 349, 364, 373	Components	385
BS 4675	250	Centrifugal pumps for handling solids	23	Compressed air-driven diaphragm pump	45
BS 4683	270	Centrifugal pumps for pulp	23	Compressed air-driven rotodynamic submersible pumps	16
BS 4999	267	Ceramic rolling-contact bearing	10	Compressibility	59, 140
BS 5257	250, 384	Ceramics	215	Computational fluid dynamic (CFD)	374
BS 5316	386	Certificate of Conformance	296	Computer simulation	288
BS 5345	63, 94, 270	Certification	270, 296, 297	CONCAWE	62, 94
BS 5500	204, 383	Certification authorities	380	Concentration measurements	122
BS 5555	388	Chains	188	Concrete cleaning	41
BS 5750	386	Chalk	334	Condenser extraction	26
BS 5857	122	Changes of state	56	Confirmation tests	294
BS 5908	62, 94	Channel impellers	25	Connection to process pipework	289
BS 6199	123	Charpy	292	Connections	385
BS 7405	123	Chattering	283	Constant speed AC motors	270
BS 7929	217	Check valves	160	Construction projects	356
BSI British Standards	94, 381	Chemical applications	11	Contactors	265
Buckling pin relief valve	283	Chemical bellows seal	238	Container emptying pumps	47
Buffer liquid	231				
Burner oils	68				
Bursting discs	139, 283				

Contaminated water	15	Design variations	230, 236, 243	Drinking water	16, 64, 182
Continuity equation	96	Det Norske Veritas	380	Drive train	338
Contraction pumps	53	Detergent	360	Drive train efficiency	322
Control valves	160, 172, 184, 185, 198	Determination of shim thickness	255	Drivers	3, 337
Controlling authorities	265	Dewatering techniques	356	Drivers for pumps	262
Conversion factors	394	Diaphragm coupling	251	Basic electrical theory and principles	262
Cooling categories	267	Diaphragm dosing pumps	371	Engines	275
Cooling fans	322	Diaphragm pumps (includes mechanical and hydraulic actuation)	44, 45, 46	Maintenance	275
Copper	204, 206	Diaphragm spacer coupling	258	Motor selection illustration	276
Copper alloys	67, 209, 210	Diesel engines	190	Motor starters	273
Copper concentrate	334	Differential head	31, 127	Motor types	270
Corrosion	204, 218	Differential head or pressure	330	Noise	275
Corrosion fatigue	218	Differential temperature	363	Power recovery turbines	276
Corrosion rate	218	Diffuser pumps	17, 19	Regulations and standards	265
Corrosion resistance	48, 208, 223, 293	Dilutant liquids	58	Turbines	276
Corrosion testing	219, 220	Dimensions and performance	384	Useful references	278
Corrosive effects of unknown materials	224	DIN	381	Drums	20
Cost of energy	198	DIN 740	250	Dry motors	5
Costs	183, 184, 185, 187, 245, 257	DIN 3990	282	Dry running	28, 150, 234
Coupling alignment	304, 308	DIN 5440	6	Dry running seals	234
Coupling calculations	250	DIN 24256	384	Dry solids (DS) content-value	74
Coupling hubs	252	DIN 31001	258	Dry-pit pumps	22
Coupling spacers	312	DIN 50049	296	Ductile iron	206
Couplings	189, 322, 338	Direct current DC	262	Ductility	7, 292
Crankcases	205	Direct flow regulation	198	Duplex stainless steels	7, 20, 43
Creep	205	Direct-acting process pumps	40	Duty and capabilities	331
Creep resistance	204, 292	Direct-acting reciprocating pumps (includes pneumatic, hydraulic and steam actuation)	47, 228	Duty cycle	3, 4
Creep testing	292	Direction of rotation	269	Duty point	23
Crevice corrosion	218	Direct-on-line (DOL) starting	178, 186, 250, 274, 347	Dye penetrant inspection	293
Crude oil	15, 26, 358	Disc pumps	31	Dynamic load ratings	361
Crude oil burning engines	190	Discharge pressure	31, 330	Dynamic viscosity	392
Crude oil production	40	Discharge valve	46	E	
Current meter	121	Disengaging couplings	248	Earth moving	40
Cyclone separator	232	Dismantling	312	Eccentric gear pumps	35
Cylinders	221, 223	Displacement pumps	28	Eccentric screw pumps	4, 35
D		Dissolved and entrained gases	150	Economics	318
D-A pumps	47	Distribution of water	348	Economic efficiency	353
Dairy industry	27, 39	District heating	318	Eddy current couplings	188, 189
Dairy products	313	DN 250	285	EEMAC	266
Dampers	187	Documentation	297	EEMUA	266
Dangerous liquids	27	Domestic heating	384	Efficiency	193, 265
DC motor control	272	Domestic water	4	Efficiency factor	324
DC motor drive	197	Dosing diaphragm pumps	371	EHEDG	387
DC motors	192, 264	Dosing errors	371	Ejectors	4, 50, 126, 228
Dead head	4	Dosing pumps	177, 289, 313	Elastic properties of some liquids	59
Deep well ejector	11	Double Disc pumps	45	Elastomer bellows	237
Deep well pumps	16	Double gear coupling	250	Elastomers	36, 38, 45, 214, 215, 240
Deep well pumps with ejector	51	Double mechanical seals	360	Electric current	262
Deep-groove ball bearings	361	Double seal systems	369	Electric motor noise	275
Pump terminology and definitions	3	Double seals	237	Electric motors	133, 337, 365, 387
Deformable particles	71	Double suction axially-split pumps	332, 346	Electric submersible pumps	15
Delicate solids	25	Double suction pumps	8	Electrical units	262
Demand/supply variations	323, 326	Drain cleaning	41	Electrically driven sump pumps	356
Demineralized water	63	Drain rim	280	Electrolytic (galvanic) corrosion	218
Dense, thin films	217	Drain water	73	Electromagnetic flow meter	118
Dense-pulp pumps	37	Drainage	356	Electromagnetic pollution	387
Density	58, 392	Drainage pumps	26	Elongation	292
Derived units	389	Drilling mud	49	EN 733	6, 344, 384
Desalination	19	Drilling waste	358	EN 809	258
Descaling pumps	41			EN 953	258
Design principles	234			EN 1672	27
				EN 10204	296

EN 13951	386	External gear pumps	31, 49	Food and live fish	355
EN 14343	386	External systems	232, 240, 244	Food and pharmaceutical industries	366
EN 22858	249, 384	F		Food processing	27, 313, 355
EN 24006	123	Face loading	235	Food processing industry	25
EN 29000	386	Factors influencing choice	258	Food processing operations	75
EN 50014	63, 94	Fatigue strength	292	Foodstuffs	386
EN 50020	63	Ferritic steels	67	Foodstuffs industry	37
EN 50028	63	Filtering	73	Foot valve	151
EN 50039	63	Fire fighting pumps	4, 12, 13	Force	392
EN 50014	270	Fire hazardous liquids	270	Forces and moments	385
EN 50018	270	Fire precautions	383	Foundations	304
EN 60085	269	Fish pumping	25, 71	Foundation bolts	280
EN ISO 748	123	Fixed costs	319	Francis turbine	31
EN ISO 5167	123	Fixed irrigation pumps	6, 7	Free-flow pumps	25
EN ISO 6817	123	Flame-proof motors	270	Frequency inverters	272
EN ISO 8316	123	Flange specifications	217	Frequency regulated induction motor	197
EN ISO 9908	6	Flange standards	385	Fresh water	64
EN ISO 12100	258	Flange-mounted motors	305	Friable particles	71
EN ISO 21049	246	Flanges	385	Friction drives	188
EN ISO 22858	344	Flexible pipes	357	Frictional loss diagrams for water	109
End-suction centrifugal pumps	39	Flexible power transmission	35	Frictional loss diagrams for oil	112
End-suction multi-stage peripheral pumps	30	Flexible shaft couplings	254	Frictional loss diagrams for normal pulp	117
Endurance run	295	Flexible spring coupling	251	Fruit	25, 71
Energy	393	Flexible vane pumps	38	Fuel oil transfer	30
Energy conservation	328	Flingers	228	Functional testing	295
Energy consumption	194	Floating ring seal	374, 377, 378	Furanes	213
Energy costs	198, 318, 321	Flooded suction	4, 16	G	
Energy Equation	98, 127	Flotation	73	Galvanic corrosion	218
Energy recovery turbines	361, 362	Flow	96, 330, 393	Gas drying	43
Energy Saving Trust (EST)	321	Flow and pressure pulsation	142	Gas engines	190
Energy savings	199	Flow diagrams	143	Gas flow	75
Energy utilisation	352	Flow losses in pipe systems	309	Gas handling test	294
Engine driven self-priming pumps	358	Flow meters	118, 349, 364	Gas leakage	359
Engine oils	69	Flow meters for open channels	120	Gas seals	238
Engine-driven self-priming pumps	17	Flow monitoring	371	Gas sweetening	43
Engineering plastics	17	Flow rate	126	Gas turbines	190
Engines	197, 280, 337	Flow regulation and control	176, 263	Gas-charged dampers	287
Engines and gas turbines	311	By-pass return	186	Gaseous state	56
Enhanced Capital Allowances (ECA)	320	Choice of flow regulation method	197	Gases	56
Environment	338	Flow regulation	177	Gaskets	211
Environmental hazards	60	Infinitely variable speed	188	Gear couplings	257
EPA	381	Introduction	176	Gear pumps	4, 31, 126, 139, 144, 334
Epicyclic gearboxes	282	Multi-speed gearboxes	184	Gearbox oils	69
Epoxy resins	213	On-off control of constant speed pump	178	Gearboxes	134, 184, 188, 276, 338
Equipment positioning	364	Pole-changing induction motors	182	Gentle handling	25, 36
Equivalent pipe length	116	Throttling by control valve	184	Gentle pumping	319, 335
Erection and installation	338	Useful references	201	Germanium	211
Erosion	107	Variable flow requirements	176	Gilsonite	334
Erosion and corrosion	375	Flow regulation efficiency	322	Glandless pumps	24, 27
Erosion-corrosion	218, 219	Flow variations	179, 286	Glass beads	221
Estimated profits and service life	321	Flow velocity in pipes	107, 108	Glass fibre	232
Ethylene glycol injection	43	Fluid	4	Glass fibre reinforced PTFE	38
Ethylene propylene	215	Fluid couplings	188, 189	Gorator pumps	25
Ethylene propylene diene (EPDM)	48	Fluidity of paper pulp	75	Graffiti removal	41
Euler's equation	129	Fluids	56	Graphical determination shim thickness	256
European Machinery Directive	382	Fluorocarbon alloys	48	Graphite	215
European standards	8	Fluorocarbons	45, 212	Graphite fibre	232
Evacuating pumps	151	Fluoroelastomer	215	Grey cast iron	34, 64, 205
Even Wall® stators	370	Flush liquid	231	Ground water	64
Excavating	16	Flushed stuffing box	231	Guarantee	151
Existing plant	327	Fly ash	334	Guards	252
Expansion vessel	350	Flywheels	179		

Gunmetal	38, 67, 210	Horizontal two-stage end-suction overhung impeller centrifugal pumps	9	Inline pumps	4, 11, 345
Gypsum	334	Horizontal two-stage end-suction pumps	10	Inspection	294
H		Horizontal two-stage radially-split centrifugal pumps	18	Installation	3
Hafnium	211	Hose pumps	126	Installation and maintenance	304
Hand-operated diaphragm pumps	356	Hot oil systems	368	Care and maintenance	310
Harbour and bridge construction	356	Hot water	350	Foundations	305
Hard metallic materials	220	Hot water pumps	5, 384	Installation	304
Hard packing	233	Hot-oil pumps	343	Pipework and pipe systems	308
Hardness	292, 394	Hot-wire anemometer	122	Tanks and sumps	305
Hardness of water	65	Hover seals	228	Useful references	316
Harmonics	316	H-Q and P-Q diagrams	134	Institution of Chemical Engineers (IChemE)	94
HART	196	H-Q characteristic	29	Insulation removal	41
Hastelloy	32, 210	H-Q curves	9, 130, 135, 136, 156, 158, 162	Integral gearing	22
Hastelloy B & C	7	HSE	381	Integrated control and diagnostics	289
Hazard assessment	60	Hub attachment	252	Intergranular or intercrystalline corrosion	218
Hazardous areas	270	Hybrid peripheral pumps	30	Internal gear pumps	32, 49
Hazardous gases	142	Hydraulic design	137	Internal inspection	293
Hazardous liquids	15, 17, 289, 319	Hydraulic diameter	101	Inverter packages	272
Hazards	60, 382	Hydraulic energy consumption	325	Investment calculation - existing plant	320
Head	4, 31	Hydraulic fluid power	49	Investment calculation - new plant	319
Head losses in fittings	100	Hydraulic gradients	168, 171	Investment calculations	201
Head losses in straight pipes	99	Hydraulic Institute	386	Investment costs	318
Health and Safety Executive (HSE)	94	Hydraulic motors	4, 49	Investment grant	320
Health hazards	60	Hydraulic performance	166, 332	Iron	204
Heat exchanger tube cleaning	41	Hydraulic power	325	Iron ore	334, 373
Heat pumps	4	Hydraulic power applications	32	Irrigation	361
Heat transfer pumps	344	Hydraulic tolerances	166, 176	ISO 1000	388
Heat treatment	293	Hydraulic turbines	4, 191, 197	ISO 1102	281
Heating circulation pumps	4	Hydraulically-driven pumps	47	ISO 1285	281
Heating systems	352	Hydraulic-ram pumps	52	ISO 2548	386
Heating, water and sanitation pumps	4	Hydrocarbon liquid fractions	26	ISO 2858	7, 26, 28, 249, 250, 333, 384
Heavy-duty applications	9	Hydrocarbon-based heat-transfer oils	343	ISO 3069	6, 7
Helical gear pumps	4, 35	Hydrochloric acid	211	ISO 3448	69, 94
Helical rotor pumps	4	Hydrocracking process	31, 362	ISO 3661	7
Helical screw pumps	4	Hydrogen sulphide	15, 142	ISO 3731	281
Heterogeneous mixtures	103	Hydrogenated nitrile butadiene rubber (HNBR)	370	ISO 4141	281
High capacity bearings	360	Hydrostatic couplings	188, 189	ISO 5167-1	119
High pressure cleaners	43	Hydrotests	217, 301	ISO 7005	216
High pressure liquids	47	Hygiene	386	ISO 8703	281
High pressure pumps	216	Hygienic-quality rotodynamic pumps	27	ISO 8785	281
High pressure segmental pumps	19	I		ISO 9000	386
High pressure supercritical recycle process	366	IEC	94, 381	ISO 13709	8, 9, 17, 19, 20, 22, 384
High speed pumps	22, 200	IEC 72	269	ISO 14159	27
High temperature protection	273	IEC 72 A	269	ISO 21049	8, 10, 238
High viscosity/large solid mixtures	47	IEC 79	63	ISO R541	119
Highly viscous liquids	333	IEC 60034	267	ISO TR 3313	122
History of unit systems	388	IEC 60038	264	ISO TR 12764	123
Homogeneous mixtures	102	IEC 60947	273	ISO TR 13593	282
Hooke's joints	35	IEEE 488	196	ISO, International Standards Organisation	265, 276
Horizontal multi-stage axially-split centrifugal pumps	19	Impact strength	292	Isolating valves	160, 366
Horizontal multi-stage radially-split centrifugal pumps	20	Impeller efficiency	128	J	
Horizontal single-stage double-suction axially-split pumps	8	Impellers	25, 129, 137, 138, 221, 229, 375	Jet pumps	30, 50, 126
Horizontal single-stage double-suction radially-split pumps	9	Induction motors	182, 263, 269	K	
Horizontal single-stage end-suction overhung impeller centrifugal pumps	6, 7, 8	Industrial oils	69	Kevlar®	212
Horizontal two-stage axially-split centrifugal pumps	17	Industrial waste	44, 73	Keys and key ways	385
		Inertial dampers	287	Kinematic viscosity	57, 392
		Infinitely variable flow regulation	176	L	
		Injector	4	Labyrinth seal	228
		Inline piston pumps	40	Laminar and turbulent flow	99
				Laminar flow	100

Lantern ring	230	M			
Large vertical multi-stage centrifugal pumps	22	Macerators	23, 53	Metal-to-metal sealing	377
Laser alignment	256	Machine tool cutting oil applications	6	Metering and dosing pumps	188
Laser mounts	280	Machine tools	40	Metering pumps (flow within $\pm 0.1\%$ to $\pm 3\%$ with substantial dp changes)	46, 49, 228, 310
Laser-doppler	122	Machinery Directive	60, 382	Methanol	142
Lead	210	Magnesium silicates	335	Methanol injection	44
Lead alloys	210	Magnetic couplings	27, 369	Microspherite	334
Length	390	Magnetic drive	228	Miller Number test	331, 334
Life Cycle Costs	128, 197, 298	Magnetic drive internal gear pumps	49	Miller Numbers	23, 71
Lifting frames	281	Magnetic drive non-metallic pumps	215	Mineral oils	68
Lifting lugs	280	Magnetic drive pumps	27, 349, 350, 369	Minerals	215
Lignite	334	Magnetic induction couplings	27	Minimum flow	167, 168
Limestone	334	Magnetic particle inspection	293	MIP test	294
Limit of proportionality	292	Magnetic protection	273	Mission valves	40, 42
Limited torque couplings	248	Magnetite	335	Mixed-flow pumps	25, 136
Limonite	334	Maintenance	232, 242, 245, 338, 377	Mixing valve	350
Linear acceleration	391	Maintenance manual	300	Mobile agricultural applications	29
Linear velocity	391	Maintenance operations	330	Mobile fire pumps	29
Linearity test	294	Maintenance schedule	314	Modular multi-stage pumps	4
Lip seals	228, 242	Manual change gearboxes	184	Modulating action	282
Liquid carbon dioxide pumps	367	Marine applications	30	Molybdenum	208
Liquid corrosion of metals	217	Marine pumps	13	Moment of inertia	251
Liquid end studs	221	Market Transformation Programme (MTP)	321	Momentum equation	97
Flow of liquids	96	Mass	392	Monel®	210
Flow measurement	116	Mass-produced pumps	216, 386	Monoblock liquid ends	42
Fundamental equations	96	Material choice	222	Monoblock pumps	4, 35
Liquid-solid mixtures	102	Material combinations	222	Motor air cooling	267
Pipe flow losses	99	Material losses	221	Motor cooling	268
Pressure losses	107	Material toughness	395	Motor energy losses	354
Useful references	123	Materials	67, 240, 337	Motor speed	263
Liquid properties	3, 70, 71, 75, 330, 331, 336, 364	Materials for pumps	204	Motor starters	178
Liquid reservoirs	324	Abrasion resistant materials	220	Motor stool	4
Liquid ring pumps	4	Conclusions	224	Motor winding insulation	311
Liquid state	56	Corrosion and erosion	217	Moulded centrifugal pumps	213
Liquid transport system	324	Introduction	204	Mounting arrangements for electric motors	268
Liquids	56	Material selection	222	Mud motors	4, 49
Liquid-solid mixtures	15, 103, 158, 326, 331	Material strength and integrity	216	Mud, drilling	334
Lloyds Register	380	Materials resistant to cavitation damage	221	Multi-lobe plain bearings	376
LNG carriers	359	Typical materials	204	Multiple pumps	176
LNG re-injection	44	Useful references	224	Multiples of SI units	388
Load/unload control	178, 186, 263, 365	Mean Time Between Failures (MTBF)	324, 330	Multi-speed gearboxes	282
Lobe pumps (including circumferential piston pumps)	36, 37, 49, 144	Mean Time To Restore (MTTR)	324	Multi-stage axial pumps	75, 151
Local environment	245	Measurement flumes	120	Multi-stage centrifugal pumps with integral gearing	22
Locked rotor torque	264	Measurement in pipe and duct systems	122	Multi-stage pumps	137, 162, 229
Loss coefficient	100	Measurement standards	122	Multi-stage segmental centrifugal pumps	18, 31
Loss of head	104	Mechanical diaphragm pumps	44	Municipal waste	44
Losses and efficiency	128	Mechanical diaphragm pump materials	45	N	
Losses in bends	108, 116	Mechanical losses	142	NACE	381
Losses in motors	265	Mechanical run	295	National Standards bodies	276
Low alloy steel	206	Mechanical seal piping arrangements	239	Natural asphalt	334
Low carbon steels	293	Mechanical seals	8, 10, 23, 34, 44, 148, 228, 229, 232, 233, 343, 359	Natural gases	26
Low pressure quench	244	Mechanical variators	188	Natural rubber	36, 215
Low pressure starting	186	Meehanite®	205	NBR rubber	39
Low shear	37	Melamine	213	Negative pressure	172
Low shear rate	355	Melting point	56	NEMA	11
Low viscosity liquids	332	Mercury cell processing	349	Neoprene®	36, 38, 45, 48, 215
LPG	142	Mercury emissions	350	Net Positive Inlet Pressure (NPIP)	146
Lubricating oil	150	Metallic bellows seals	237	Net Positive Suction Head (NPSH)	146
Lubrication	36, 231	Metallic materials	204	New and existing plant	319
		Metallic pumps	218	Newtonian liquids	57
		Metal-to-metal joints	20		

Newton's Law of Viscosity	57	Oil well fracturing	200	Pipe bend	122
NFPA	381	One-dimensional flow	96	Pipe flow	96
NFPA 30	270	Operating conditions	330	Pipe flow losses	102, 105, 325
Nickel	204, 206	Operating costs	318	Pipe friction losses	325
Nickel alloys	210	Operating efficiency	3	Pipe losses	158
Nickel aluminium bronze	66	Operational life	384	Pipeline pumps	4, 200
Niobium	211	Operational safety	3	Pipelines	326
Ni-Resist	206	Operational sequences	179	Pipes and pipe connections	337, 350
Nitric acid	211	Optical alignment	256	Pipework	224, 304
Nitrile rubber	36, 38, 45, 48, 215	Optimisation process	375	Pipework design	364
Nodular cast iron	34	Orifice plates	119	Pipework noise	108
Noise	384	OSHA	381	Piping	3
Noise and vibration	304	Outline dimensions	269	Piping design	313
Noise reduction	17	Overflow by-pass regulation	177	Piping layout	10
Noise testing	295	Overflow control	187	Piston pumps	40, 49, 126, 141
Non-abrasive solids	334	Overload protection	273	Piston seals	142
Non-clogging pumps	24	Overpressure	282	Pitot tube pumps	30, 126
Non-contacting seals	228	Oversizing	327	Pitot-static tube	121
Non-destructive testing	293	P		Pitting	218
Non-disengaging couplings	248	Packaging	294	Plitting Resistance Equivalent	68
Non-electric submersible pumps	15	Packing material	232, 244	Plain stuffing box	231
Non-hermetic pumps	343	Paint stripping	41	Plane angle	390
Non-metallic centrifugal pumps	213	Painting	295	Planning of pipework	363
Non-metallic materials	32, 204, 211	Paper	74	Plant life raw materials	366
Non-metallic positive displacement pumps	48	Paper pulp	23, 105, 116	Plastic pumps	218
Non-metallic rotodynamic pumps	26	Parallel pump operation	163	Plate valves	41
Non-Newtonian liquids	57, 160	Particle density	71	Plug valves	42
Non-return valves	160, 170, 171, 285, 309	Particle sizes	71, 103	Plug-guided ball valves	42
Non-SI units	389	Pay-off method	320	Plugs	385
Non-sparking guards	258	PD 5304	258	Plunger pumps	13, 41, 46, 49, 126, 141, 148, 242, 323, 332, 365, 366
Nozzles	119, 280	PD ISO/TR 17766	382	Plunger steam pumps	48
NPiP available	41	PD ISO/TR 17766:2005	137	Pole-changing motors	271
NPiP test	294	Peak-to-peak pressure pulsations for pipework	288	Polyester	213
NPiP, Net Positive Inlet Pressure	38, 43, 102, 146, 147	Pelton Wheel	121	Polypropylene (PP)	45, 48
NPiPa	4, 149	Penetration	58	Polytetrafluoroethylene (PTFE)	48
NPiPa/NPiPr margin	152	Perfluoroelastomer	215	Polythene manufacture	46
NPiPr	4, 41, 149	Performance and reliability	151	Polyurethane (PU)	48, 213
NPiPr surface	148	Performance curve	126	Polyvinylidene (PVDF)	48
NPSH, Net Positive Suction Head	102, 146	Performance of pumps	126	Pop action	282
NPSH/NPiP	127	Performance test	294	Porous, relatively thick films	217
NPSHa	4, 17, 20, 152	Performance testing	386	Portable engine driven pumps	44
NPSHa,		Peripheral pumps	29, 126	Portable plunger pumps	41
Net Positive Suction Head Available	146	Peristaltic and rotary peristaltic pumps	228	Portable self-priming pumps	16
NPSHa/NPiPa	107, 221, 305, 330, 364	Peristaltic hose pumps	38	Positive displacement	3
NPSHr,		Peristaltic pumps (including rotary peristaltic pumps)	38, 49, 287	Positive displacement (PD) flow meters	119
Net Positive Suction Head Required	4, 9, 22, 146	Permissible suction lift	147	Positive displacement (PD) pumps	31, 46, 75, 96, 126, 142, 160, 170, 182, 186, 188, 193, 220, 223, 258, 282, 300, 311, 331, 326, 330, 363, 365, 370
Nuclear fuel recovery	46	Petrochemical industry	254	Positive displacement medium pressure pumps	373
Nylon	48	Petrol	142	Positive displacement pump curves	143
O		Petrol engines	189	Potash	334
O rings	211, 235	pH value and choice of material	64	Potentially explosive atmospheres	270
OCMA	266	pH values	59, 223	Pour point	68
Off-road trailers	281	Pharmaceutical industry	27, 37	Power	263, 393
Offshore installations	245	Phase compensation	263	Power consumption	181, 183, 184, 186, 194
Oil	112	Phenolic resins	213	Power economy	181
Oil & Gas industry	10	Phosphate	335	Power factor	263
Oil cargo pumps	358	Physical hazards	60	Power failure conditions	170
Oil refining	31	Physical properties	292	Power loss	169
Oil refining plants	330	Physical protection	267	Power recovery hydraulic turbines	248
Oil well drilling	49	Pilot-operated relief valves	139, 283		
Oil/water emulsion hydraulics	44	Pinion pumps	4		

Power recovery turbines	321	Economic aspects of energy utilisation	352	Pump, mechanical requirements	337
Power station operation	374	Modern pumps for hydrocarbon-based and synthetic heat-transfer oils	343	Pumpability	74
Power transmission	40	Positive displacement medium pressure pump system for tube press application	373	Pumping efficiency	322, 327
Power-assisted steering pumps	33	Pumping fresh water to a high reservoir	345	Pumping food	355
Precipitation-flocculation	74	Sealing systems for thermal oil pumps	368	Pumping live fish	356
Present capitalised value method	319, 320	Updating of water supply for industrial use	351	Pumping of delicate solids	355
Pressure	4, 31	Use of engine driven self-priming pumps	358	Pumping ring	237
Pressure boosting pumps	164, 165	Pump capabilities	72	Pumping screw	237
Pressure drop	285	Pump capacity	336	Pumps and piping systems	156
Pressure maintenance	165	Pump choice	331	Multiple pump systems	162
Pressure pulsations	107, 142, 286, 288, 363	Pump curve	122	Pressure drop across valves	160
Pressure ratings	204, 363, 383	Pump curves	130	Pressure pulsations	173
Pressure surges	187	Pump economy	176	Pump hydraulic data	166
Pressure testing	294	Pump efficiencies	30	System curves	156
Pressure transducer	349	Pump efficiency	52, 128, 368	Useful references	173
Pressure vessels	206	Pump efficiency	184	Water hammer	168
Pressure, stress	392	Pump efficiency and economics	318	Pumps as power-recovery turbines	31
Preventative maintenance	312, 313	Economic assessment criteria	319	Pumps for parallel operation	285
Priming	4	Economic optimisation	318	Pumps for synthetic oils	344
Process adaptation	319	Important system characteristics	322	Purchase conditions	339
Process liquid	244	Partial optimisation	326	Purchased equipment	295
Process pipework	282, 304	Useful references	328	PVC	45
Process seal and sealing	228	Pump energy consumption	318	PVDF	45
Introduction	228	Pump faults	312	Pyrites	335
Process liquid seal selection	244	Pump H and Q at maximum efficiency	167	Q	
Process liquid seals for reciprocating rods	243	Pump losses	354	Quality Assurance	339
Process liquid seals for rotary shafts	229	Pump nominal duty point	156	Quality Assurance Manual, QAM	297
Reciprocating rods	242	Pump operating problems	363	Quality Control (QC) Plan	204, 298, 386
Rotary shafts	228	Pump out vanes	229	Quality Control or Inspection Departments	296
Useful references	246	Pump packages	4, 5, 262	Quality Control staff	386
Procurement costs	192	Pump piping	313	Quality, inspection & testing	292
Progressive cavity pumps	35, 49, 75, 144, 370	Pump selection	220, 330, 369	Guidelines for documentation	299
Properties of liquids	56	Check lists for pump purchase specification	336	Introduction	292
Explanation of terms	56	General operating conditions	330	Mass-produced pumps	297
Liquid-gas mixtures	74	Pumps for liquid-solid mixtures	334	Useful references	301
Liquid-solid mixtures	70	Purchasing	339	Quench	244
Oils	68	Selection of pump according to duty and capabilities	331	Quench liquid	231
Table of liquid properties	75	Selection of pump according to hydraulic performance	332	Quench liquid buffers	343
Useful references	94	Pump site	245	Quench systems	311
Water	63	Pump specifications	327	R	
Protection equipment	170, 172, 273	Pump speed	122	Radial bearing	10
PTFE	45, 228	Pump sump	305, 306	Radial forces	132
PTFE bellows	237	Pump terminology and definitions	3, 127	Radial misalignment	249, 250
PTO shafts	33	Pump test results	301	Radial piston pumps	40
Pull-out torque	264	Pump testing	295	Radial vane impellers	22
Pull-up torque	264	Pump theory	127	Radially-split centrifugal pumps	3, 20
Pulp and paper	361	Introduction	126	Radiators	350
Pulp pumps	23	Positive displacement pumps	138	Radiographic inspection	293
Pulps	74	Rotodynamic pumps	127	Radiographs	301
Pulsation dampers	41, 47, 102, 49, 142, 149, 179, 288, 311, 365	Suction performance	145	Rated power	269
Pulsation measurement testing	295	Useful references	153	Reactor and transformer starters	275
Pulse width modulation drives	272	Pump types	3	Reciprocating plunger pumps	366
Pump applications & solutions	343	Checklist of pump terminology and definitions	3	Reciprocating positive displacement pump theory	139
A fresh water booster station	348	Introduction	3	Reciprocating pumps	4, 140, 166, 178, 223, 221, 286, 300, 313, 316, 323, 331, 364
A small sewage pumping station	347	Other pump types	50	Reciprocating rods	243
Adjustable jet pump	351	Positive displacement pumps	31	Reduction in area	292
Cargo pumps for tankers	358	Rotodynamic pumps	4	Reference line misalignment	254
Common errors which create pump operating problems	363	Special rotodynamic pumps	29	Reference lines	255
Detergent manufacturing systems — pump installations	360	Useful references	53	Refineries	254
Digital controllers for diaphragm dosing pumps with speed-controlled drive motors	371	Pump unit	4, 280	Regenerative pumps	29
Domestic heating systems and pumps	350				

Regulation efficiency	182	Screws	385	Shape, hardness and abrasiveness	71
Regulation system schematics	195	Sea-water pumps	19	Shear pin and buckling pin relief valves	283
Relative density	58	Seal cartridge	25	Shear pin valve	283
Reliability	384	Seal cavity dimensions	385	Shear sensitive solids	39
Relief valves	139, 311	Seal face material	240	Shear stress	99, 106
Relief valve operation testing	295	Seal harnesses	240	Shim thickness	255
Remote monitoring	378	Seal piping arrangements	240	Ship bilge pumps	200
Repairs	293	Seal with circulation	236	Ship hull cleaning	41
Repeatability test	294	Seal without circulation	236	Ships' pumps	66
Reseat pressure	282	Sealed magnetic couplings	28	Short circuit protection	273
Resistance	275	Sealing	228	Shut-off head	157
Resistance temperature detectors, RTDs	273	Sealing solutions	245	SI system	387
Reverse by-pass	172	Sealing systems	368	SI units	56, 389
Reverse flushing	310	Sealless positive displacement pumps	49	Side channel pumps	4
Reverse osmosis, (RO)	19, 31, 44, 63, 362, 371	Sealless pumps	29, 39	Sight glass	122
Reverse rotation	173	Seals	211	Silicon	207
Reverse running	171, 269	Seat flatness	235	Silicon carbide	215
Reverse running centrifugal pumps	361, 362	Seawater	13, 66, 217	Silicon carbide bearings	343
Reynolds Number	58, 99	Seawater and corrosion	66	Silicon iron	207
Rheology	334	Secondary gas seals	239	Silicon nitride	215
Rigid screw pumps	33	Sedimentation velocity	105	Silicones	213, 215
Rigid vane pumps	37	Segmental pumps	11	Similarity	131
Ring section pumps	4	Selective corrosion	218	Single Disc pumps	44
Road making	16	Selenite	334	Single phase AC	262
Rock blasting	16	Self-priming	4, 40, 150, 313	Single phase canned motor	270
Rod seals	242	Self-priming pumps	5, 14, 17	Single pipe system	156
Rolling bearings	9	Self-priming test	295	Single seal for slurries	236
Root vegetables	25	Self-venting	150, 313	Single seal with flushing	236
Rotary eccentric piston pumps	39	Semi-rotary hand pumps	52	Single seal with quench	237
Rotary hand pumps	52	Separate pumps and motors	305	Single-stage centrifugal pumps with integral gearing	22
Rotary peristaltic pumps	39	Series pump operation	162	Single-stage end-suction pumps	27
Rotary piston pumps	36	Serpentine	335	Siphoning	4
Rotary positive displacement pump theory	138	Service life	321	Site clearing	16
Rotary positive displacement pumps	144, 314	Set pressure	282	Site facilities	3
Rotary pumps	4, 139, 300	Sewage	44, 71, 73, 182, 310, 334, 335	Site simulation test	295
Rotodynamic pumps	243, 244	Sewage handling pumps	24, 34, 200	Siting	304
Rotodynamic pump curves	133	Sewage pumping station	347	Size, speed and pressure	244
Rotodynamic pump efficiency	195	Sewage systems	318	Sizing non-return valves	285
Rotodynamic pump theory	127	SG iron	206	Sizing of a piping network	160
Rotodynamic pumps 3, 4, 98, 126, 136, 160, 163, 166, 167, 169, 173, 182, 184, 187, 208, 219, 220, 229, 250, 276, 299, 311, 315, 332, 335		Shaft alignment	252, 253	Sizing pipes	107
Rotodynamic pumps without drivers	29	Shaft bearings	376	Sizing the by-pass	187
Rotor	35, 38	Shaft centre heights and tolerances	385	Sizing the control valve	185
Rubber cladding	221	Shaft couplings	248, 252, 258, 386	Skids	17, 280
Rubbing speeds	139	Choice of coupling	257	Sliding bearings	17, 20
Run dry	34	Environment	251	Sliding shoe pumps	37
Running tests	294	Forces and moments	250	Sliding vane pumps	37
Rupture discs	283	Installation and disassembly	252	Slipring induction motor	197
Rutile (titanium dioxide)	334	Introduction	248	Slipring motors	271
S		Machinery guards	258	Slow-closing valves	179
Safety of electrical equipment	383	Misalignment	249	Sludge	15, 73, 306
Safety of machinery	387	Service factors	250	Small centrifugal pumps	4
Safety switch	274	Service life	252	Small flow changes	186
Sand	335	Shaft alignment	254	Snoring	4, 45
Sanitary PC pumps	370	Size and weight	251	Soap powder manufacture	44
Santoprene®	48	Speed	251	Sodium hydroxide	349
Scotch Yoke	44	Types of coupling	248	Soft drink manufacture	46
Screen mesh	310	Useful references	258	Soft packings	228, 229, 230, 243
Screw centrifugal impeller pumps	355	Shaft end dimensions	385	Soft start system	178
Screw pumps	34, 126, 143	Shaft misalignment	250	Soft starts	274, 365
Screw-centrifugal pump	25	Shaft power	168	Soft-packing	9
		Shaft sealing	9, 18, 34, 268	Soil sewage	73
		Shaft seals	24, 32, 228, 229, 337, 377, 385		
		Shale	335		

Solid coupling	250	Steelworks hydraulic power supply	365	Temperature	204, 330, 393
Solid shaft couplings	248	Stellite®	232	Temperature classification	269
Solid sizes	24	Stiction	106	Temperature considerations	236
Solid state	56	Stocking spare parts	316	Terminal markings	269
Solidifying point	68	Stopping problems	183, 184	Testing standards	386
Solid-liquid mixtures	358	Stopping/unloading	179	Therban®	370
Solids	56	Storage volumes	180, 183, 184	Thermal oil pumps	368
Solids concentration	71	Streamline	96	Thermal overload protection	275
Solids handling	31, 37	Stress-corrosion	218	Thermal protection	273
Solids handling pumps	23, 24, 43, 358	String testing	295	Thermistors	273
Solids properties	336	Strip inspection	295	Thermoplastics	212
Solubility in H ₂ O	75	Stubble burning	16	Thermosetting plastics	213
Sour water	26	Stuffing box packing	142	Thermostat valves	351
Spacer coupling	359	Stuffing boxes 32, 34, 41, 45, 142, 229, 231, 243, 311, 316, 385		Thixotropic liquids	58
Spare parts	312, 316	Styrene butadiene rubber	215	Three pump system	360
Specific speed	131	Submerged pumps	359	Three-phase squirrel-cage induction motors	271
Specification compliance	266	Submersible non-clogging pumps	25	Throttle regulation	177, 179, 184
Speed range and efficiency	194	Submersible pumps	14, 15, 271, 306	Throttle valves	160
Speed regulated pumps	192	Submersible pumps for deep well applications	16	Throttling	198
Speed regulation	198	Submersible pumps with electric motor	15	Thrust bearings	10
Speed-controlled drive motors	371	Submersible sump pumps	356	Thyristor controllers	194
Spheroidal and nodular cast iron	206	Suction and delivery pipes	308	Tilting pad thrust bearings	17, 19, 376
Split seals	238	Suction isolating valve	286	Time	391
Spray drying	46	Suction lift	152	Titanium	32, 211
Spring-loaded relief valves	283	Suction pipework	14, 364	Torque	264, 392
Squirrel-cage motors 3, 31, 133, 148, 168, 263, 271		Suction piping	17, 313	Torque converters	188, 189
Stainless steels 18, 32, 38, 43, 45, 67, 208		Suction pressure	330	Torque transmitters	189
Standard ISO 2858 pumps	8	Suction stage	4	Torsionally flexible shaft couplings	249
Standard motor pump units	353	Suction valve plates	221	Torsionally rigid flexible couplings	248, 249
Standard pumps to EN 733	6	Sulphuric acid	211	Total head losses in the pipe system	102
Standard water pumps	6	Super stainless steels	18, 209	Tracers	122
Standardisation	245	Supercritical extraction service	366	Trailers	281
Standards, units & conversions	380	Surface flatness	234	Transfer pumps	200
SI, The International System of Units	387	Surface inspection	293	Transmission efficiency	200
Conversion factors for SI units	389	Surface water	64, 73	Triple lobe pumps	360
Normal quantities and units used in pumps technology	396	Surge	107	Triple screw pumps	28, 34, 49
Other conversion factors	394	Surge arrester	173	Triple-rotor and 5-rotor screw pumps	34
Standards	380	Surge columns	172, 179	Trouble-shooting 233, 242, 296, 298, 314	
Useful references	396	Surge tank	172	Trouble-shooting guide for soft packing	233
Stand-by pumps	324	Suspensions	56, 326	Tube press processing	373
Star-delta (S-D) starting	178, 182	Swirl flow meters	120	Tungsten carbide	211
Star-Delta (Y-D)	274	Switched reluctance motors	22, 191, 272	Turbine meters	119
Starting	183, 184, 265	Symbols and numbers	388	Turbines	31, 197, 338, 362, 374
Starting/loading	178	Symbols for different pump types	196	Turbining	4, 49
Static delivery head	325	Synchronous motor	270	Turbo-expanders	191, 197
Static head	31	Synthetic fibres	232	Turbulent flow	219
Static seal rings	236	Synthetic oils	344, 343, 368	Turbulent flow in pipes	99
Static suction head	152	Syringe pumps	44, 49	TÜV point	375
Stators	35, 37	System characteristic	127	Twin screw pumps	75
Stator technology	370	T		Twin-geared screw pumps	26
Steady flow	168	T-02-09	27	Twin-rotor screw pumps	34
Steady state accuracy test	294	Tailings	335	Two phase flow	34
Steam jet pumps	51	Tandem bellows seal	368	Two-stage pumps	18
Steam or gas turbines	305, 318	Tank residue disposal	44	U	
Steam turbine driven cargo pumps	359	Tankers	358	Ultimate strength	292
Steam turbines	3, 190	Tanks	121, 224	Ultrasonic inspection	293
Steam-driven pumps	47	Tantalum	211	Ultrasonic meters	119
Steels	32, 43, 64, 66	Tar sand	335	Unbalanced phase detection	275
Steelmaking	40	Tariffs	321	Units used in pump technology	396
Steelworks	182	Telemonitoring system	378	UR heat treatment process	361
Steelworks descaling	365				

Urea	213	Venting	4, 311	Waste water pumps	4
Urethane	215	Venturi meters	119	Wastewater treatment	361
Urethane rubber	221	Vertical dry-pit pumps	13	Water	108, 109
US National Fire protection Association	63	Vertical inline pumps	11	Water extraction plant	351
V		Vertical multi-stage centrifugal pumps	11	Water hammer	160, 170, 181, 187, 346
Vacuum pumps	4	Vertical plunger pumps	41, 335	Water injection	44
Valve characteristic	161	Vertical single-stage overhung impeller centrifugal pumps	11	Water jetting	44
Valve closing time	171	Vertical single-stage overhung impeller centrifugal pumps for general applications	10	Water preparation	46
Valve flow losses	141	Vertical single-stage pumps	10	Water supply for industrial use	351
Valve material loss	71	Vertical turbine pumps	4	Water supply pump packages	5
Valve pressure drop	161	Vertical wet-pit pumps	13	Water/oil emulsion	365
Valves in pipework	309	Vessel cleaning	41	Wear	27, 33, 36, 43, 220
Vane pumps	37, 75, 126	Vibration	22, 308, 384	Wear in reciprocating pumps	142
Vaned diffusers	19	Vibration of pipework	107	Wear in rotary displacement pumps	139
Vanes	121, 229	Vibration testing	295	Wear ring material	223
Vapour pressure	56	Vinyl ester resins	213	Wear rings	10, 17, 129
Variable frequency inverters	168	Viscosity	57, 68, 75, 143, 330, 363	Wear-resistance	221
Variable frequency motors	271	Viscosity corrections	137, 143, 144	Weirs and notches	120
Variable orifice or aperture flow meters	120	Viscous	160	Weld procedures	301
Variable ratio coupling	196	Viscous crude oil pipelines	44	Welding	293
Variable ratio transmissions	188	Viscous liquids	333	Wells	26
Variable speed AC motors	271	Viton®	38, 48	Wet motors	5, 28, 268
Variable speed control	351	Vitonâ	36	Wet rotor	270
Variable speed DC motors	272	Voltage	264	Wet rotor circulation pumps	352
Variable speed drivers	189	Voltage regulated induction motor	196	Wet rotor motor pump units	353
Variable speed pumps	156	Volume	391	Wet-pit pumps	22
Variable system curves	157	Volumetric efficiency	128, 140	White asbestos	232
V-belts	24, 134, 281, 338	Volumetric flow	126, 371	Whole-life costs	318
VDI 2060	250, 251	Volute pumps	19	Wing-guided valves	42
VDMA 24296	316	Vortex shedding flow meters	120	Wire-to-water efficiency	128
Vegetable fibres	232	Vortexes	306	Witnessing	296
Vegetable oils	68	W		Works Certificate	296
Velocities in pipes	309	Wall thickness	216	Works Report	296, 297
Velocity	73	Wash water pump packages	11, 12	Z	
Velocity head	31	Waste water	73	Zinc	210
Vendor Document Requirement	386				
Ventilation	304				

Index to advertisers

ABS Group	xxiii
Allidos Ltd	xix
Allweiler AG	ii
Börger GmbH	xii
Burgmann Industries GmbH & Co KG	226
Dawson Downie Lamont Ltd	xxviii
Dickow Pumpen KG	xiv
Feluwa Pumpen GmbH	xix
Flo-Dyne Ltd	xvii
Grundfos	viii, ix
ITT Fluid Technology	Outside Back Cover
Junty Industries Ltd	xix
Kächele GmbH	xxvi
Kestner Engineering Co Ltd	xxviii
Metso Minerals (Sala) AB	x
Milton Roy Europe	xvii
Morgan AM & T	vi
Netzsch Mohnopumpen GmbH	xxi
PCA Engineers Ltd	vi
PCM	xii
Savino Barbera	xiv
Toyo Pumps Europe	iv
Ture International (SEOCA)	Inside Front Cover
Uraca Pumpenfabrik GmbH & Co KG	xxi
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