INJECTION MOLDING HANDBOOK

THIRD EDITION

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Summary

Injection molding is a major worldwide business. As Fig. 17-1 summarizes there is an interrelationship among all plastic processing methods, all the molded products, and applications in all types of industry.

The Most Important Forming Technique

Although just over a century old, relatively new when compared to other processing techniques and materials, the technique of injection molding is regarded as being the most significant and rational forming method there is for nonmetallic materials. A major part in this development has been played by the forward-thinking machinery industry, which has been quick to seize on innovations and incorporate them into its products. This has afforded users every opportunity to exploit this universal method of production to its fullest advantage, which is precisely what they should do. Quality and, not least, price will continue to be the major criteria determining the competitiveness and performance of an injection molding company (1, 17).

Neither the manufacture of individual components nor even the material-oriented application of plastics will in the future form the focus of plastics activity, but rather efforts will be concentrated on finding the most rational means of manufacturing an end-product. For years the only rich source of new developments resided in product innovation, such as reducing the number of components by making them able to perform a variety of functions or making the fullest use of materials' attributes. Process innovation is now also moving to the forefront worldwide.

Process innovation includes all the means that help tighten up the manufacturing process, reorganizing and optimizing it. The core of all activity has to be the most efficient application of production materials, a principle that must run right through the entire process from the raw material to the finished product. This also has to include the adaptation of capacity to cope with other semifinished products and achieving the best possible flow of materials with the greatest possible flexibility. The aim is no longer merely to manufacture particular components of a particular quality, but to manufacture a finished product in the most rational way possible.

Other new factors enjoy recognition, such as shorter delivery times, faster adaptation to alteration wishes, and a willingness to keep customers informed on how an order is progressing. Just-in-time (JIT) delivery, statistical process control (SPC), or more simply, computer-aided design (CAD) are terms taken from the international vocabulary that have become synonymous with future competitiveness for injection molding firms, terms that at the very least point to

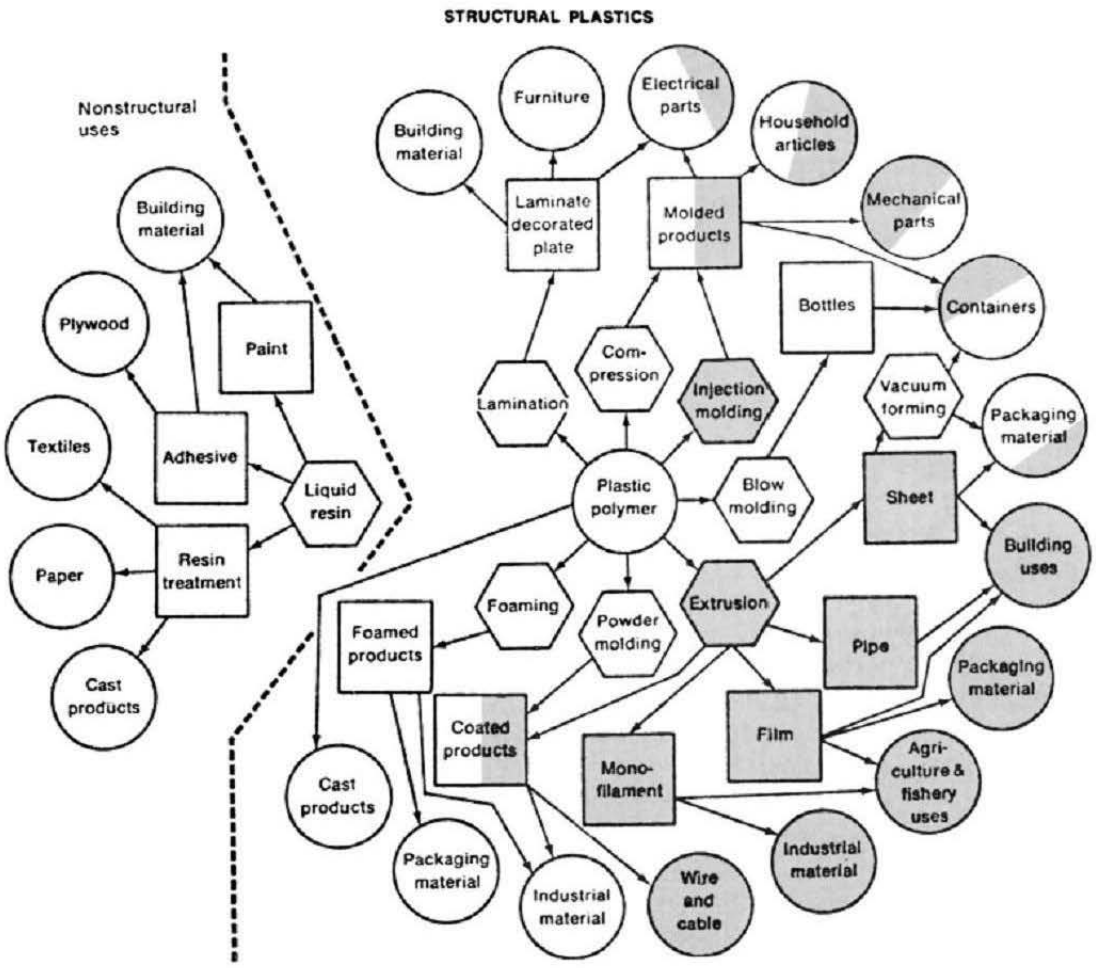


Fig. 17-1 Interrelation among processes, products, and applications.

where the future lies for the injection molding industry (82, 104).

Major manufacturers are already well underway with the development of a logistic chain of manufacturing installations, raw materials supply, finished molded parts, and data relevant to the production process. Production cells where other work steps follow the actual injection process right up to storage ready for transportation are becoming more and more common practice.

Major increases in future production can only be achieved once injection molding firms also come to regard themselves as a system in its own right that has to be made to work to maximum efficiency. An integral feature of this is the complete chain of operations ranging from organization and the flow of materials to guaranteeing quality, possibly also including documentation for the customer and finally punctual delivery without causing excessive intermediate and final storage problems for the manufacturer.

Tough competition worldwide forces injection molding operations to push through extensive rationalization measures. Punctual delivery from storage facilities bursting to capacity can no longer be the principal aim of molded parts manufacturers. Production must rather be made flexible to a degree that even permits the production of small batches of various molded parts at short notice with as little stockkeeping as possible and minimal loss of time and materials.

Even if modern injection molding machinery with all its ingenious microprocessor control technology is in principle suited to perform flexible tasks, it nevertheless takes a

whole series of peripheral auxiliary and secondary equipment (Chap. 10) additions to guarantee the necessary degree of flexibility. These include, for example, (1) tool-changing devices for injection molding machinery, including rapid clamping and coupling equipment; (2) tool transport facilities; (3) tool preheating banks; (4) cylinder-changing devices; (5) handling equipment, particularly robots with inter-changeable arms allowing adaptation to various types of production; (6) raw material supply systems; and (7) transport systems for finished parts and handling equipment to pass molded parts on to subsequent production stages.

Processing Trends

The progressive development of production technology over the past century has been characterized by the introduction of new materials and also the exploitation of novel application opportunities with the increasingly stronger interlinking of individual working processes and production steps (58). Thus, injection molding is an integral part of a manufacturing process; it has been and will continue to be progressive. This development has been driven ahead by the economic necessity for creating new production equipment (Chap. 15). The term *value creation* (VC), which could possibly be defined as achieving certain proceeds per labor unit, machine, or materials and energy used, became a focal point.

Increasing the creation of value is the basis for economic growth and therefore raising of the material living standard of the population worldwide. This requires systematic rationalization measures in every production area of the economy. Because their basic substance is derived from polymeric petroleum or natural gas derivatives and also because of their time- and temperature-dependent material properties, these "new" materials could not be compared with any other group of materials regarding their processability. Therefore, new processing methods and machines had to be developed step by step. This is characterized, in particular, by the combined pressure and temperature loading applied during the actual injection molding process.

Parallel to the development of principles in plastics technology, a revolution in production methods took place in other manufacturing areas and the mass production of cars in particular, as well as electrical engineering or machine construction. Its aim was the increasingly closer interlinking of sequential processing operations following onto each other.

Production of single units has been and still is being pushed ever further into the background in favor of integrated production systems. The composite production unit may consist of the same kind of machinery, a single but more highly integrated machine, or even several different construction units.

All efforts in this area were made with the aim of reducing the production cost or increasing the created value. This development also established itself in the production sphere of plastic articles toward the end of the 1970s. Since that time, a gradual advance in the increase of injection molding production density has been discernable. Four goals have been pursued.

The first has been a reduction in setup times (this goal continues) by employing fast-molding clamping systems, including all service connections and couplings (ejector couplings). This goes hand in hand with the standardization of all adapter plates and clamping aids and a reduction in the number of machine models and sizes available. Endeavors to reduce the number of operators resulted in the development of parts handling equipment (PHE) to demold parts. Closely following was the introduction of depositing technology. It started with an indexing conveyor belt adjacent to the machine. However, as the majority of robots possess a sufficiently high degree of positioning capacity, as well as a highly developed electronic control system, the next step in a production line can take the form of registered, stacked depositing on pallets or in cages next to the machine.

The ultimate target of stage I may well be the equipping of independently operating production islands with the facility of fast mold changing and orientated deposit

of articles in containers. Integrated, indirect quality control using the process parameters control as a reference variable is now state of the art.

Next, linking up the production islands with all the equipment into a material flow system represents another important goal. This concerns all measures rendering the production islands independent of constant, manual intervention by an operator. These actions may consist of the plotting, monitoring, storage, and possible alteration of the process parameters of an injection molding machine, as well as its peripheral equipment by a production master computer.

Yet another step would be the installation of a central raw materials conveying system, operating in the same way as a finished article transporting system (driverless floor-bound transport system, roller track system, overhead conveyor for transporting pallets, cages, cardboard boxes, etc.) treated as computer-controlled production units (Chaps. 9 and 10).

Even the supply of auxiliary material can be organized in a similar manner. For instance, the next change of tools for the injection molding machines and gripper heads for the handling unit required for a new production run can also be taken to the machines by their own transport system from a computer-monitored store. A computer for production planning concerning purchasing and sales dispositions could be shared and combine all production island computers.

Another criterion is flexibility, which is being demanded with ever greater emphasis. The increasingly stronger integration of plastics moldings applications into mass production requires the just in time (JIT) concept to be put into practice to as great an extent as possible.

The third goal involves (1) self-optimizing the injection molding machine, (2) integrating quality control and documentation, and (3) making the supplier responsible for quality. An increased volume of items can pass through automated processing and assembly facilities. At the same time, reducing the number of components kept in the end-processor's goods-in stores requires 100% quality assurance to be supplied, because of the brief residence time before the articles are assembled. The responsibility for this and obligation to piece-by-piece quality assurance documentation become an ever more important requirement demanded of the supplier (Chaps. 12 and 13).

The injection molding machine of the future will contain further process models in addition to those employed today for the closed-loop control of all parameters that determine the product characteristics. These process models will be able to establish machine-setting data through postprocessors directly from the design drawing and restrict the presently applied tolerance bands even further during a production run (geometry tolerance band smaller than 0.5%; that for weight smaller than 0.15%). This will be made possible by changes in drive concepts and through the possibility of advance calculation of the article dimensions during every injection cycle, plus appropriate adaptive options for accessing the closed-loop process control system (Fig. 1-26).

Data thus established can be recorded and attached to the products in the shape of statistical process control protocols. However, it is not just indirect (cost-effective) quality control whose development is being furthered; this also applies to direct quality control, through the linking of handling units and downstream optical systems for the automatic registering of surface blemishes and dimensional deviations.

The suitability of these optical systems for cycle-integrated contour measurement is being improved increasingly through the development of more efficient picture chips and the connection with microcomputers of greater computing capacity for image processing. A further decisive advantage being opened up by modern optical systems is the possibility of identifying inserts faster, even if supplied haphazardly to a handling unit facilitating their safe positioning in the injection mold. To achieve this goal, endeavors should be made to develop closer functional compatibility between peripherals.

Equipment will be more compact in the future. Examples of this are the integration of

mold-changing systems and service couplings into the injection molding machine, the reject baffles in the machine's discharge chute, or the increase in the number of handling axes.

The fourth goal includes processing technological innovation for increasing the integration. Owing to the identifiable connection between labor costs and automation equipment, there is at present an ongoing development in the sphere of production technology, primarily within the scope of integration of production technology. However, it will not be possible to continue saving on production personnel forever as it will become necessary to have a minimum number of operators even in an extensively automated shop. The potential for process innovation (also all measures for improving the production technology) will have been utilized as far as possible in the medium term at least once integration of production technology has been completed.

Any other increase in value creation thereafter will only be possible by the even-further-reaching integration of production steps or through innovations in processing technology.

Integration will have the farthest reaching online production as its ultimate goal, that is, the direct further processing of a plastic article after demolding through assembly to other finished products into functional units. Production by injection molding will increasingly become less of an island within the overall production plant. Departmental boundaries will become even more obscure. The shortest distance to the complete product will be highlighted more emphatically still. Material flow will be speeded up and shortened.

Further advances can be expected in the sphere of processing technology. New processing methods include the direct backing-injection of textiles for decorative automotive components, for chairs, etc.; the "outsert" technology for producing metal body parts with surface-injected plastics functional components; and the "gas-melt" process for material-saving through the systematic creation of hollow cores in moldings by introducing an inert gas during mold filling. These innovative processes will also to an increasing extent incorporate multicolor or coinjection molding, as well as more advanced insert technology and the wider use of liquid plastics, as expected in the future (Chap. 15). They will furthermore embrace the processing of water-soluble plastics for all these applications, in which complicatedly shaped hollow spaces in injection molded articles have to be demolded, which would be impossible to achieve with conventional molding technology.

Productivity

Injection molding of plastics is characterized by its rapid expansion not only in output, repeatedly molding to tight tolerances and meeting performance requirements, but also in processing of new types of plastics to continue the further incursion of plastics into all markets (474). Plastics are among the nation's most widely used materials, surpassing steel on a volume basis (see Figs. 17-2 & 17-3) and world consumption of steel, aluminum, rubber, copper and zinc by volume and weight. When including all world materials, those listed in Fig. 17-3 represent about 10% of total global material consumption with wood and nonmetallic earthen (stone, clay, glass) materials, each at 45%.

Plastic products and materials cover the entire spectrum of the nation's economy, so that "fortunes" are not tied to any particular business segment. Thus, plastics are in a

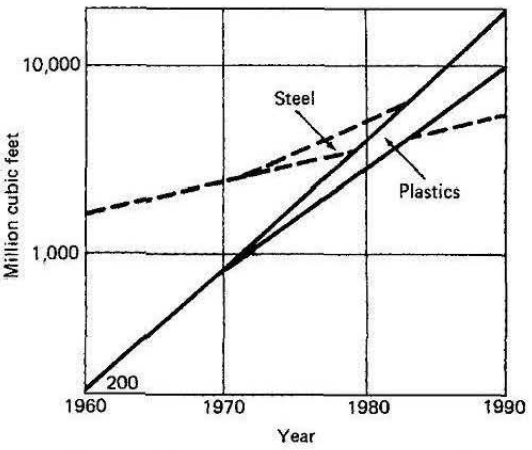


Fig. 17-2 World consumption of raw materials by volume.

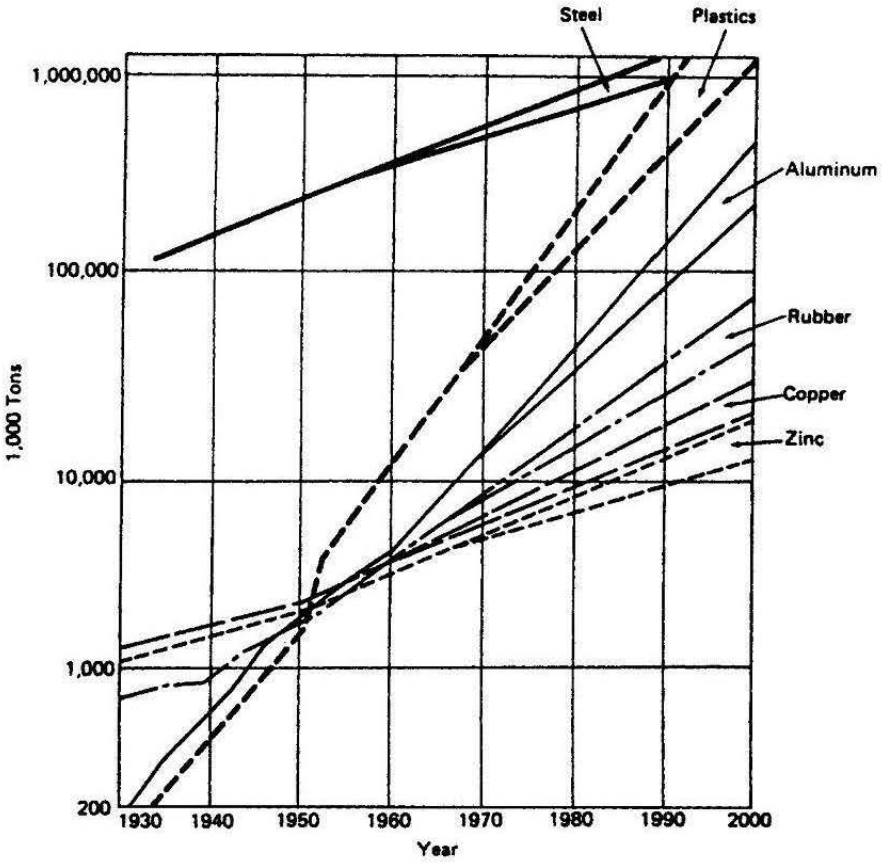


Fig. 17-3 World consumption of raw materials by weight.

position to benefit by a turnaround in any one of a number of areas: packaging, transportation, housing, automotive, and many more industries.

In any particular technological sphere such as injection molding, an appreciable advance in knowledge is hardly possible in the long run without related progress in other fields. Indeed, the incentive for further development is often provided by forces not subject to scientific laws. In some branches of plastics technology, particularly the field of processing techniques and machine construction, it was originally sufficient to adapt existing equipment, at that time devoted mainly to rubber and thermoset plastics processing. The new thermoplastics had a wider range of working temperatures and viscosities compared with rubber, but it was soon recognized that they required individual treatment in process design because of their special processing characteristics and wide application potential.

It eventually became clear that very little was known about what was happening inside the familiar processing machines—for example, in the flights of a screw. Only with the beginning of a deeper understanding of process mechanisms and their underlying physical laws (gained through close cooperation between theorists and technologists) has plastic processing technology and machinery design made any real progress.

The 1940s, 1950s, and 1980s were the most productive periods in the latest phase of injection development, which at last became the province of the scientific engineer rather than the craftsman. The many publications of recent years describing investigations of the rheological and thermodynamic phenomena occurring during the injection, with their considerable use of mathematics, can be appreciated only by a limited circle of specialists. In spite of what has been achieved so far, the industry has surmounted only the first hurdle of systematic development. The present

state of injection design and technology must not be regarded as the last word in progress. On the contrary, there are great possibilities in development, many of them still dormant, that must be recognized and examined with the close cooperation of theorists and technologists.

The increased use of injection molding is due to the development of the reciprocating screw as well as process control, and, more recently, a better understanding of the basic molding factors that involve cost advantages and market requirements.

It is important to understand that manufacturing process and processing conditions have an influence on the properties of plastic molded products. The injection molding process can be subdivided into individual operations, for which machine-independent processing variables can be determined from the machine settings (operating parameters), as reviewed throughout this book. These calculations are based on the assumption of process models for each operation, into which the corresponding values of the machine setting parameters are inserted.

These process variables are first correlated with the internal structure of the plastic material, which represents the key for the behavior of the molded product. This is followed by a second step in which the relationships are derived between structure and the properties of the end-product.

Machine Aging

To ensure the maximum efficiency performancewise and costwise of plastic products, new machines and auxiliary equipment are continually being developed. The processor must keep up to date on improved fabricating processes or risk the consequences (Fig. 17-4). Given the local and worldwide competitive situations, the success of an injection molding operation depends on having the most up-to-date equipment (Fig. 17-5).

Modernizing injection molding plants is an endless procedure. The IM business continues to make useful sweeping changes in both technological and business areas both locally and worldwide. The marketplace continues to be transformed. The U.S. plastic industries have about 10,000 plants and many of these plants are always updating their equipment and taking advantage of processing newer and more profitable plastic materials.

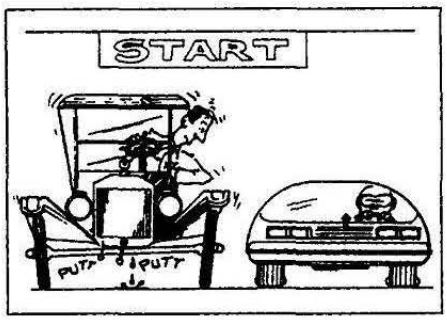


Fig. 17-4 You cannot expect to compete with a machine built to today's standards and capabilities.

With the new modern injection molding machines used in a rather long production run, the cost of running the machine per part is usually 5 to 10% of the part cost. This cost advantage usually also exists in smaller runs. Of the approximately 75,000 injection molding machines still in operation in the United States, more than half were built before 1980—and many of those prior to 1970.

Some of these old machines may lend themselves to rebuilding or remanufacture. Another way to upgrade the performance of existing machines, so long as they have microprocessor controls, is to link them to a plantwide statistical process control system, which costs less than a single new machine (Chap. 13). However, an investment in new machines need not entail out-of-the-ordinary costs to achieve new levels of modernization.



Fig. 17-5 No I cannot be bothered to see any crazy salesperson since we have a battle to fight.

Increasing numbers of molders are seeking to broaden their capabilities by acquiring their first small presses. Still others are looking to cut operating costs by shopping for presses with energy-saving features. Note that in the United States, the cost of electrical energy is nearly half that of Europe.

Some injection molders refuse to operate a machine beyond a certain number of years. Others follow a program of regular refurbishment in order to keep machines working like new or even better than new. Still others simply run their presses relentlessly until they become unrunnable. There is, in short, a wide range of attitudes toward machinery modernization. Molders required to maintain strict accountability for part quality look for statistical process control features that other processors may dismiss. Molders with limited access to investment capital may find the remanufacture of some of their equipment a more attractive option than those who can afford to replace all of a plant's old injection molding machines with new equipment.

Modernization can be eminently practical for obtaining machine features that cut back on utility bills, or for adding small press capability to make job scheduling more efficient. Or, in the case of new super-fast onboard machine controls, modernization can involve a venture into the leading edge of technology (Chaps. 7 and 9).

Response to Change

A manufacturing plant is a system composed of the complete molding operation. Its maximum productivity can be attained only if the whole system works effectively and efficiently. Also, the whole system must be responsive to change, and it must evolve and improve with time. But today's approach to manufacturing automation treats manufacturing as a conglomeration of individual systems such as inventory, purchasing, shop control, and accounts payable. In fact, there are over fifty individual areas of manufacturing that can be profitably automated. The problem is to get everything to work together: to integrate the pieces into a whole that is larger than the sum of the pieces.

Across all manufacturing systems, there is only one basic common denominator: data. Planning for manufacturing automation must focus on data as the key to systems integration. Only in this way can manufacturing engineers and management avoid the problems of integration as an after-the-fact phenomenon of almost impossible magnitude. This is especially true if management intends to buy standard software to perform individual system functions. Defining data requirements is indispensable to successful automation planning.

The natural outcome of data requirements planning is a database definition. This definition, if it is properly developed, can first be implemented on a database management system (DBMS) and then interfaced with the multitude of current and future application systems needed by the users. The problem is to obtain a good data requirement definition first. To do so, it is important to understand the basic business processes that this database must support and then extrapolate a precise definition of the data requirements. Throughout this book, reviews are provided on the type of databases required.

It is meaningless to try to define all the data that will be used by all the systems that will ever be needed. What is crucial is to identify the data that everyone uses, that is, the common data. All else is private data, to be used by individual departments. This common database is the critical path to all automation, and it must be effectively automated. If a business fails to automate its common data or it does so in piecemeal fashion, it will never get anything to function well together.

But what do those data look like? To understand that, we must delve into the inner workings and hidden mechanisms of manufacturing planning and control systems. We must understand how data evolve in manufacturing from an elementary manufacturing control system to a fully automated factory. To accomplish that, we will look at both manufacturing planning and the complete molding operation.

The need for improved productivity sometimes reflects a need for better management. A wide assortment of symptoms could

indicate the need to improve plant performance: Backlogs building up, output falling short of requirements or expectations, costs getting out of line, and quality levels declining.

The problem is by no means limited to the molding industry. Business pages are full of reports on how companies are responding to such pressures in today's economic climate. Some managers are staking their futures on newer, high-tech equipment, hoping that microprocessors and push buttons will produce a competitive edge. Others are carefully studying their current organizational structure, procedures, and management environment. Long-overdue adjustments are taking place, resulting in rather dramatic turnarounds. It is unfortunate that a near-crisis situation is required to assure some managers that courageous actions must prevail over complacency.

Be aware that bringing a new high-tech machine into a poorly managed environment will only guarantee that it too will suffer the same delays and poor handling as those already in place.

For example, many molding operations are scheduled on a three-shift basis with the potential for optimum utilization of equipment capabilities. However, some can be readily classified as true round-the-clock operations, whereas others are merely running for three consecutive single shifts.

What makes the difference? It all boils down to management controls. If the machines can achieve an uninterrupted transition from shift to shift and continue to run through rest and lunch breaks, they are indeed in a position to attain their optimum potential. However, if the machines shut down 15, 20, or even 30 min before the end of the shift for reasons of report writing, cleanup, or lack of incentive, with a 15-min or so delay in getting started on the next shift, lost momentum and output can never be regained. The same is true for idle break periods.

Poor time management is often associated with lack of recognition of the "one best way" to do a job and inadequate training in consistent working procedures. Between-shift shutdowns do not provide an opportunity for the two operators to exchange information about machine conditions or problems in running an order. Infact, the oncoming operator may delay the start of his or her shift further by adjusting or modifying the previous setup. To make matters worse, operating procedures may fail to require a new approval of output when production is resumed on the new shift.

Managers who seek the optimum utilization of their resources must be constantly aware of plant work habits, which sometimes drift away from their objectives without constant monitoring. Some operations lend themselves to such simple procedures as a worker watching another's machine when that person is away from his or her station. Others train operators of related tasks to step in at such times. Some plants employ floating relief operators. Still other plants schedule an extra quarter- or half-hour overlap period for their machine or line people so there can be an orderly transition and exchange of information. The relieving operator comes in early and takes over to keep the machine running without interruption. Remember, transforming a lost hour into a productive one will gain about 300 h per shift annually, with a value of $9,000 per shift or $27,000 for a three-shift operation on a machine at a $30/h rate.

Also, the often mentioned need for production standards exists, based on realistic utilization and output expectations, to signal unacceptable performance. Reliable, timely reporting and hands-on observations would monitor nonproductive delays. Unfortunately, this time-management problem of missing existing productivity improvement opportunities is quite common. Potential advantages to be gained by asking questions, keeping informed, taking nothing for granted, and a willingness to make changes in current operations may at times approach those to be gained by upgrading equipment.

In any event, buying new equipment will not change a poor working environment. In the order of priorities, setting one's house in order first will usually require less capital than purchasing new equipment and guarantee faster, more lasting returns. You cannot solve the problem of a poorly managed shop with a new machine.

Despite the growth and prosperity of the plastics industry, which includes injection molding, many "wrong turns" have been made to produce parts, which have resulted in added expenses and usually limited use of the product. There is an unfortunate tendency to jump from theory to theory while supposedly solving each molding problem as it arises, rather than evaluating the entire system to see why the problem existed in the first place. There is a practical solution: A logical, back-to-basics approach (as reviewed in this book) can be used.

Process and Material Selections

Selection procedures have been reviewed throughout this book, particularly in Chaps. 1 (Summary), 2 (Guide to IMM Selection), and 6 (Material Selections). Any selection has to be based on the complete detailed requirements that have to be determined for the product to be molded. Another important factor is to compare injection molding with other processes. A guide to examples of factors to be considered is provided in Chap. 16. As reviewed in Chap. 5, it is important to interrelate whatever other action is required such as proper design of product and molds, meeting processing functions, etc. (Fig. 17-6).

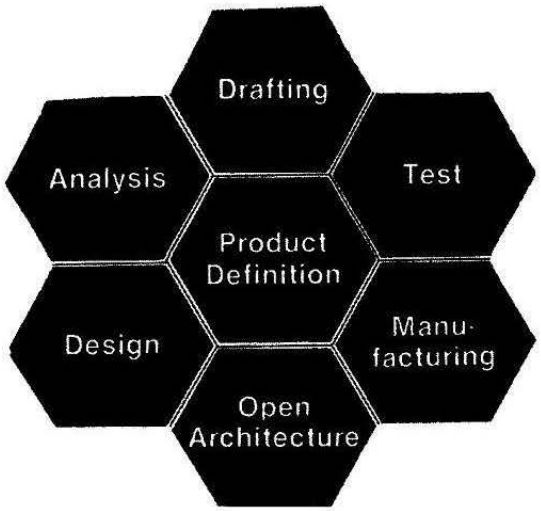


Fig. 17-6 Factors that produce the molded product meeting performance and cost requirements.

Plastics and Equipment Consumption

Plastic consumption by the basic processes in producing products is estimated at 36 wt% by extruders, 32 wt% by injection molding, 10 wt% by blow molding, 8 wt% by calendering, 5 wt% by coating, 3 wt% by compression molding, and 6% other. Thermoforming, which is the fourth major process used, consumes about 30% of the extruded sheet and film, which principally goes into packaging.

At least 65 wt% of all plastics require some type of compounding. They principally go through compounding extruders, usually twin-screw extruders, before going through equipment such as IMMs to produce product (3). It is estimated that in the United States there are about 18,000 extruders, 80,000 injection molding machines, and 6,000 blow molding machines producing about one-third of the world's plastic products. For the 80,000 IMMs the usual report shows that 30% are under five years old, at least 35% are five to ten years old, and the rest are more than ten years old.

Machinery Sales

In mid-1999 the Freedonia Group Inc. (Cleveland, OH, tel. 440-646-0484) Plastics Processing Machinery predicted that U.S. machinery sales demand will rise at 5.8% per year to $1.5 billion by year 2003. IMM is the largest category, accounting for 51% of all machinery sales. By 2003 sales of blow molding machines will grow the fastest, reaching $505 million, extrusion will reach $440 million, and thermoforming will reach $455 million. The Freedonia Group also reported that there are now over 350 U.S. machinery builders with five accounting for 50% of sales (361).

Trends in Machinery

It is essential to be aware of the fact that in reviewing developments in the machinery industry, it is not technology alone that is the driving force. The shape of the plastics

industry is partly determined by two factors: advances in technology and the interrelations between business philosophies of the manufacturers as determined by their markets. The conclusion may be easily drawn that the plastics machinery industry develops a diet of technical and market compromises (7).

The worldwide plastics machinery business has divided itself up into three style and geographic groups: United States/Canada, Europe, and the Asia/Pacific basin, with the other geographical regions, with a few exceptions, serviced from those bases. As might be expected, there are peer groups within those mentioned where a particular country or region seems to prevail. For example, Germany (and this includes the former East block) produces the majority of plastics-processing machines in Europe by value and number, Japan dominates the Asian region, and it is only the United States that has a completely amorphous spread.

Although injection molding machinery is the highest value market, as far as the basic method of operating or its principle is concerned, it tends to be the most static of the processing technologies. The process has remained basically the same since the 1950s: A pair of platens contain the mold and plastic melt is fed from a reciprocating plasticator. It is the peripheral activities and hardware that have kept the process so buoyant. Meanwhile, changes in business arrangements and company realignments have occurred.

In Europe, manufacturing groups must over the next few years begin to utilize and exchange technologies and machinery styles with the other major trading blocks. For example, Japanese machinery in the standard Asian form is unacceptable in Germany, but plastic technologies such as clarifiers, which are used in polypropylene medical grades and other esoteric additives, are generally of Japanese origin.

A partnership exists between Husky (Canada) and the Japanese industrial group, Komatsu. They offer a range of small machines but started machine-building operations in Luxembourg and initiated comanufacturing contracts with EPCO (United States) and plans to manufacture machines of up to 4,000 tons. Sandretto (Italy) started manufacturing in the United States, and Engel (Austria) has also established in the United States a plant to complement their wholly owned subsidiary in Canada. Meanwhile, the concept of "fortress Europe" is also spurring an interest in joint manufacturing via the European community.

In Italy, the Formea group has integrated the Sandretto and Metalamechanica companies, who produce around 3,000 machines a year between them, and the Mannesman group with Demag and Kraus Maffei. The plastics machinery market and demonstrated technology of the United States and Canada are at times difficult to understand or explain.

European and Japanese machine suppliers are singularly successful in the U.S. market. The claim made periodically that such success occurs as a result of injection molding machinery dumping is not borne out by the facts. In fact, it would appear that the imbalance in the U.S. machinery business is a direct result of the overseas companies intelligently interpreting the technological requirements of their chosen market. By a combination of studying the market and then bringing the appropriate technology to bear, the United States has proven to be a soft market for the import of plastics-processing machinery and designs, while at the same time some key, home-based injection molding machine makers have ceased trading, notably Reed Prentice and Stokes.

The essential factors in machine production are these. Just one company in Japan, Nissei, produces more than 3,500 injection molding machines per year. Taiwan, which is often disregarded as being not well respected in the industry, has one company, Fe Chen Shine, producing almost 2,000 machines a year. The cold reality of this is that the United States produces less than 2,000 injection molding machines, but it purchases at least twice that number from overseas manufacturers. Purchasers in the United States have demonstrated a preference for non-U.S. machinery.

Computers and Injection Molding

Plastics have not been safe from the effects of the computer explosion, fortunately. The precursor of the art, solid-state controls, was on the point of being universally accepted in the late 1960s, when the Danish company Buhl offered to subsupply any machine maker with a tailored computer package.

Sandretto were the first machine-building company not to ask a premium for fitting a computer, and this offer resulted in the image and profile of this modest and then not particularly remarkable machine range becoming the talk of the industry. Other manufacturers followed suit very quickly, with proprietary systems from Buhl, Phillips, General Electric, and Schliecher as suppliers, and the machine constructers Arburg, Battenfeld, and a few others developing their own software.

At a time when there was a lack of serious improvements in injection molding design, the introduction of applied computing technology did and still continues to add interest to the subject of injection molding. The overall computing techniques and peripherals of CIM integration and SPQ protocols (Chap. 13) are the most significant addition to the art of machine production since the introduction of the inline reciprocating screw on a production injection molding machine by Ankerwerk in the 1950s.

Interfacing Machine Performance

To injection-mold all sizes, shapes, and weights of parts to meet all types of performance requirements, the plastics industry has made steady progress in advancing the state of the art and science of injection molding over the past century. This book has reviewed many new developments that have improved the complete injection molding process. These advances have been based on knowledge gained in understanding the parameters involved in meeting part performance requirements. These parameters include:

1. Setting up specific performance requirements
2. Evaluating material requirements and molding characteristics
3. Designing parts based on the material molding characteristics
4. Designing and manufacturing molds based on part design
5. Setting up and operating the complete injection molding machine line so as to meet mold and materials processing requirements
6. Testing and providing quality control of incoming materials, materials during processing, and molded parts
7. Interfacing all these parameters by using the simplified computerized program(s) available

Injection molding machines and all types of auxiliary equipment used in the complete molding line can be installed with computerized controls to meet manufacturing requirements. Terms such as open and closed loop, analog, proportional, digital, servohydraulics, and process control, as well as the product names used by the machinery producers, tend to confuse the molder rather than provide clear technical definition. This book provides information to help eliminate this confusion.

The molder should clearly define the requirements that injection molding machines must fulfill according to production requirements. On this basis, the selection of equipment is made with the appropriate control system (30). In most cases, these requirements have changed over the past few years. In the past, the technical solution of a production problem was often the main consideration, and the production costs were of lesser importance. Today, the molder, as usual, is faced with continuously rising costs that can rarely be transferred completely to his or her customers. Hence, rationalization and cost reduction in the production area have become very topical.

In pursuit of such a policy, total automation in the manufacturing of bulk products has become essential. In this respect, it is necessary to consider not only the single production

machine but also the complete production area. The injection molding machine should be regarded as one element within an interconnected production system, which must be operated with a minimum of people; this is of even greater importance when three-shift staffing is used.

Fully automated production from raw material to the finished product requires not only a very high degree of reliability of the machine and its component parts but also the use of monitoring functions, which are employed to monitor machine performance as well as component quality. Ideally, auxiliary equipment should also be included in the monitoring systems, as it forms as essential a part of the complete production unit as the machine.

In addition, optimum utilization of the existing production equipment becomes even more important. This can mean that the mold clamping force and other machine parameters are utilized to their maximum values and that cycle times are shortened as much as possible without allowing any reduction in the quality of the articles. However, the closer one gets to these limits, the more important is the high consistency of the moldings produced.

Molding in an Industrialized Country

To survive in the future, molders must look to their skills in order to meet the existing challenge of responding to the worldwide up and down cycles of business. At the same time for many years, some molders have been in a dilemma. When they serve their customer well and the customer prospers, they could be sounding their own death knell. As the shipments to the customers grow, their very success might be encouraging the customer to replace them and do the molding in-house (7).

Perhaps nowhere has this been more feared than in supplying the automotive industry. This fear appears justified if one looks simply at the number of injection molding machines that automobile producers have installed in their own plants over the past decade. However, a closer scrutiny reveals that the in-house capacity installed is still considerably smaller than the total growth of this market sector. While taking on some work in-house, manufacturers will always look to the molding trade for the more difficult jobs, especially those requiring a strong technical capability.

This situation serves to solidify a general philosophy for molders: Anyone can literally pour plastics into a machine and press a button, and there will always be some ready to take this type of action. But the price of such an approach is less and less interesting to a molder faced with the costs of running an efficient shop in an industrialized country.

More than ever today, molders have to look to their technical skills if they are to survive and be profitable. It is a classic argument involving the unique selling point (USP). There are many and increasing opportunities for a genuine plastic USP to be exploited. The following section provides a summary checklist on skills regarding the molder.

Compromises Must Frequently Be Made

Since modifying plastic properties or machine process controls affect some end-product properties (and also certain processing factors) favorably and others unfavorably, frequent compromises are inevitable in injection molding.

One such case is the influence that a number of resin properties and machine conditions exert on flow, warpage, and shrinkage. A decision may have to be made as to which of these three consequences is the most disturbing and should be decreased (or, occasionally, increased).

Mold cycle time is often considered the most important factor in determining both resin type and operating conditions. Obviously, the faster the molding cycle time, the more economical the molding process, other factors remaining equal. However, desired properties of the molded item must be considered; frequently, a compromise must be found.

Since gloss and piece detail on the one hand and economy on the other are caused to move

in opposite directions by varying certain factors such as melt temperature and mold time, it is often essential to make a compromise between gloss and maximum economy (minimum mold cycle time).

Another compromise concerns the temperatures involved—both melt and mold temperatures. Whereas generally higher melt temperatures improve appearance, they also increase mold cycle time. This gain makes a compromise necessary between product appearance and economy.

Generally, gloss and resin processability move in one direction when strength properties and environmental stress crack resistance move in the other. This often requires a compromise.

One such compromise has to do with the resin melt index. For example, a low melt index could mean high resin viscosity and thus reduced processability, but it also improves environmental stress crack resistance and impact strength (toughness). However, low flow resins, though having high inherent resistance to environmental stress cracking, are more likely to acquire residual stresses in the molding process. This might make higher-melt-index resins preferable. Thus, here too a compromise must be reached before the molder decides which resin melt index is most suitable for mass-producing a molded item. Frequently, only a real test with the molded product in use can answer the question of whether the melt index chosen will yield the desired properties.

In this book, numerous problems have been discussed and solutions offered. However, each case must be handled individually. With the innumerable variations in equipment and resins that exist today, even a seemingly straightforward problem could easily be complicated by the application of an improper solution.

Standard Industrial Classification

The standard industrial classification (SIC) system published by the U.S. Department of Commerce classifies all manufacturing industries and services produced in the United States (transportation, communication, electronic, plastic, etc.). Their digital numbering system follows a pattern that provides input–output (I/O) detailed information data. Basically the I/O program determines what each of about 470 product level industries consumes from each of the other 370 industries. The manufacturing segments of the plastics industry are in the major group numbers 28 (chemicals and allied products) and 30 (rubber and miscellaneous plastics products). Included in the four-digit listings are SIC 2821 (plastic materials), SIC 3081 (unsupported plastic film and sheet), SIC 3084 (plastic bottles), SIC 3086 (plastic foam products), SIC 3088 (plastic plumbing fixtures), and so on.

Plastic Industry Size

Plastic products are ranked as the forth largest U.S. manufacturing industry, behind motor vehicles, petroleum refining, and automotive parts, and are growing at three to four times the rate of other national products. Plastic is followed by computers and their peripherals, meat products, drugs, aircraft and parts, industrial organic chemicals, blast furnace and basic steel products, beverages, communications equipment, commercial printing, fabricated structural metal products, grain mill products, and dairy products (in 15th place). At the end of the industry listings are plastic materials and synthetics in 24th place, paper mills in the 25th ranking. Total sales for the category of plastic products and plastic materials is now well over $275 billion/year. Machinery sales in the plastic industry are estimated to be above $7.5 billion/year.

The U.S. economy has been changing (as first reported at least to me during 1939 in college, but actually beginning at the start of the twentieth century) from a manufacturing society to an information and service society. In 1998, the U.S. Department of Labor reported that about 93 million people are not in manufacturing but rather are in an information and services. Despite this situation the U.S. plastic industry continues to grow. In the mean time

corporate consolidation of the custom injection molders continues. The successful consolidation via acquisitions, mergers, or some other form of strategic alliance of custom molders has led to immediate enhancement to its value-added product services.

Energy and Plastics

There are always improvements to be made in machines and equipment in the plant, whereby energy savings can be obtained with a net savings in total production costs. But sometimes equipment can be made more energy efficient and a condition during molding will cause a total increase in cost (as, e.g., if cycle time increases).

However, if we study the relationships of plastics and energy savings versus the use of practically any other material (Fig. 17-7), plastics conserve energy in significant ways. Energy is saved in the service life of the plastics product. Energy is also saved in shipping and maintenance, since plastics are lightweight and require less fuel for shipping and are inherently inert to chemicals, rot, mildew, corrosion, and hostile environments. Another important aspect of their use is that as new markets for plastics are developed, new ways to save energy are found in all phases of the manufacturing process and in performance.

Of the many uses of petrochemicals, the production of plastics materials is the most ingenious. The versatility of these long-chain macromolecules of basic elements combined to make diversified products is testimony to the imagination and talents of those within the industry. As compared to more than occasional serendipity or accidental discovery of new products just a few decades ago, today's research and development emphasis is on materials engineering and processing innovations. The plastics industry's research frontiers continue to be in multipolymer alloys, conductive polymers, biomaterials, and high-strength, lightweight reinforced plastics and composites. These goals reflect the industry's commitment to the conservation of energy and resources and will contribute significantly to the quality of life in tomorrow's society.

It is important to evaluate how much energy a machine requires for its operation. Injection molding tends to be energy intensive for converting plastics resin to a finished product. It requires not only the energy used

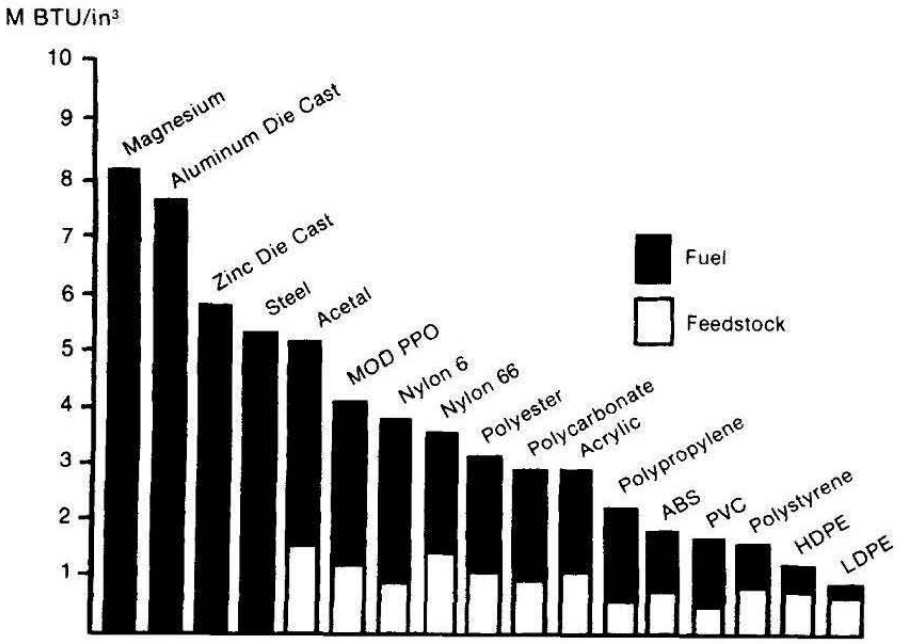


Fig. 17-7 Energy requirements for different materials.

by the machine to drive the motor or motors for hydraulic power but also the energy for the heater bands to melt the resin.

Then there is the problem of removing the heat generated in the hydraulic system by using water in the heat exchanger, and water is also needed to cool the mold to remove the heat from the plastic. This water can be from a city system, and depending on the machine size and mold and the water temperature available, as much as 20 to 30 gal/min could be required, thus creating a sizable water bill. Most plants have acquired their own wells, or closed systems using cooling towers, chillers, and the like. These require pumps and motors, plus, in the case of chillers, compressors as well.

Machine grinders are quite often used, plus materials handling equipment, conveyors, etc. In all, a considerable energy is used for the process.

It is estimated that the cost of energy will double in the next decade. This being the case, the molder is faced with two problems. First, of course, on new machinery purchases, one should buy the most energy-efficient machine available. This is a long-term investment, so that price alone or any other single reason is not justified when the long-term use of energy is considered. Also, a machine that is not energy efficient may be difficult, if not impossible, to resell a few years later. No one can go out and replace all of his or her machines with energy-efficient ones, a situation that leads to the second problem: We must reduce the energy used on present equipment, a strategy definitely employed by the machinery builders and those supplying components to the machine builders.

Plastics have many advantages. In recycling processes they have the lowest consumption of about 2 MJ/kg (2 to 2.5 MJ/I) and the highest recovery energy content of about 42 MJ/kg. Some comparisons are as follows: (1) Processing waste paper requires 6.7 MJ/kg and as a general rule about twice as much paper is needed compared to plastics for comparable applications. (2) In glass production, if one uses about 10% of recycled glass, this only reduces the energy consumption of the process by about 2%; thus the use of recycled glass requires about 8 MJ/kg, but the comparative figure is higher when considered in relation to each product, as one needs about 10 to 20 times as much material compared with plastics. (3) The energy requirement for processing scrap steel and tin-plate is about 6 MJ/kg. (4) Aluminum recycling requires about 50% of the energy needed to make a product from virgin aluminum, about 50 MJ/kg.

Insulation is the largest single application for recycled plastic (practically any types) and/or virgin foam with building insulation being one of its most significant markets. These plastics provide low thermal conductivity resulting in significant energy savings.

Plastic Data: Theoretical Versus Actual Values

During 1944 through the laws of physics, chemistry, and mechanics, theoretical property values were determined for different materials. Since that time the values for steel, aluminum, and glass have remained practically the same. However, for plastics such as PE, PP, and PA, significant improvements in material properties have been made (as predicted in 1944). The "normal" plastic properties reported were based on plastic material available at that time (Table 17-1). With the passing of time, plastic properties (strength, modulus, etc.) have significantly increased from 10 to 50% but have not yet reached their theoretical potential (1, 10, 13, 18, 45).

When the United Kingdom developed polyethylene (then called polythene) during 1944, reports received by D.V. Rosato from the U.K. physicists predicted a tremendous potential for its improvement. Out of that general purpose PE many different types have been developed and used worldwide (LDPE, HDPE, UHMWPE, etc.) (45).

Markets

Practically all markets use injection-molded plastics. Examples of these markets

Table 17-1 Comparison of the theoretically possible and actual experimental values for modulus of elasticity and tensile strength of various materials[a]

	Modulus of Elasticity			Tensile Strength		
		Experimental			Experimental	
Type of Material	Theoretical, N/mm² (kpsi)	Fiber, N/mm² (kpsi)	Normal Polymer, N/mm² (kpsi)	Theoretical, N/mm² (kpsi)	Fiber, N/mm² (kpsi)	Normal Polymer, N/mm² (kpsi)
Polyethylene	300,000	100,000	1,000	27,000	1,500	30
		(33%)	(0.33%)		(5.5%)	(0.1%)
	(43,500)	(14,500)	(145)	(3,900)	(218)	(4.4)
Polypropylene	50,000	20,000	1,600	16,000	1,300	38
		(40%)	(3.2%)		(8.1%)	(0.24%)
	(7,250)	(2,900)	(232)	(2,300)	(189)	(5.5)
Polyamide 66	160,000	5,000	2,000	27,000	1,700	50
		(3%)	(1.3%)		(6.3%)	(0.18%)
	(23,200)	(725)	(290)	(3,900)	(246)	(7.2)
Glass	80,000	80,000	70,000	11,000	4,000	55
		(100%)	(87.5%)		(36%)	(0.5%)
	(11,600)	(11,600)	(10,100)	(1,600)	(580)	(8.0)
Steel	210,000	210,000	210,000	21,000	4,000	1,400
		(100%)	(100%)		(19%)	(6.67%)
	(30,400)	(30,400)	(30,400)	(3,050)	(580)	(203)
Aluminum	76,000	76,000	76,000	7,600	800	600
		(100%)	(100%)		(10.5%)	(7.89%)
	(11,000)	(11,000)	(11,000)	(1,100)	(116)	(87)

[a] For the experimental values, the percentage of the theoretically calculated values is given in parentheses.

include packaging, building and construction, agriculture, appliances, automotive, aerospace, cosmetics, dental, drugs, electrical and electronics, furniture, horticulture, industrial, mechanical, medical, pipe, public transportation, recreation, toys, surface and underwater devices, and so on.

Injection-molded products fit in an overall scheme in processing plastics to produce different products. Figure 1-2 relates the flow ("tree flow") of processed plastics to the marketplace. Combining this "tree flow" approach to the complete molding operation (Fig. 1-1) provides the basis for fabricating products very efficiently both costwise and performancewise. One should recognize that the first to market a new product captures 80% of the market share. The young tree cannot grow if it is in the shadow of another tree or if it does not keep up with its competition. Figure 17-8 relates to this market share. A guide to marketing based on markets, plastics, and process is summarized in Fig. 17-9.

There are many applications for which plastics are the most efficient functionally and costwise. Many innovative and complex products, such as digital video disks (Chap. 15), are feasible with plastics. A few of the more important emerging products are highlighted.

Packaging

The packaging industry is the major outlet for plastics using principally extrusion and injection molding processing methods. It consumes about 25 to 30 wt% of all plastics. Figure 17-10 provides an example used to identify the type of plastic used in containers. Plastics in handling food provide

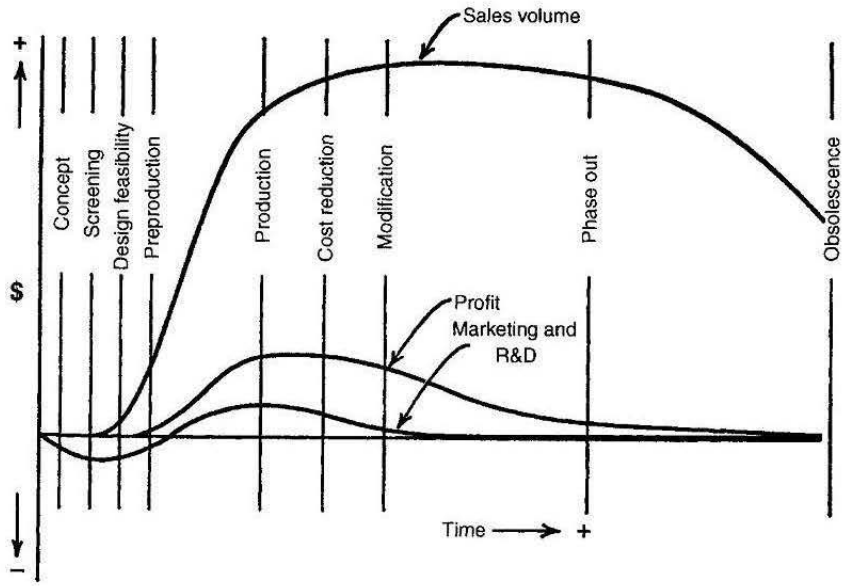


Fig. 17-8 Example of factors to consider in marketing a product.

all kinds of advantages. If plastic packaging were not used, for example, the amount of packaging contents (food, etc.) discarded from just U.S. households would more than double.

Plastics are the most efficient packaging material because of their higher product-to-package ratio as compared to other materials. One ounce of plastic packaging can hold about 34 oz of product. In comparison one ounce of aluminum packaging can hold 21.7 oz, paper—6.9 oz steel—5.6, and glass—1.8. Products are very diversified. Packaging includes products used for beverage bottles, containers, electronic devices, drugs, dual-ovenable trays, tamper-proof caps, aseptics,

- Past, present, and future growth markets for plastics.
- Improve product viable cost-to-performance with quality control.
- Current requirements, changes, and trends on the latest developments that influence markets.
- Advantages and disadvantages of plastics.
- Capitalize on use of plastics more effectively.
- Feedstock, energy, and government regulations status.
- Relate product failure to cause based on plastics, process, design, and/or life cycle.

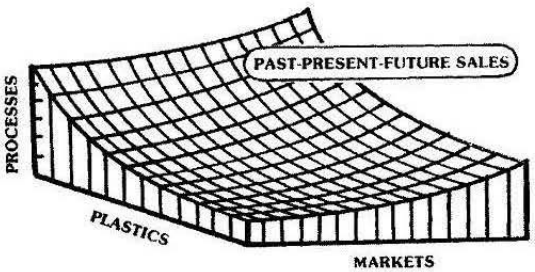


Fig. 17-9 Guide to marketing based on markets, plastics, and process.

Code		Material
1	PETE	Polyethylene terephthalate (PET)
2	HDPE	High-density polyethylene
3	V	Vinyl/polyvinyl chloride (PVC)
4	LDPE	Low-density polyethylene
5	PP	Polypropylene
6	PS	Polystyrene
7	Other	All other resins and layered multimaterial

Examples of container code system for plastic bottles. The stand alone bottle code is different from standard industry identification to avoid confusion with registered trademarks.

Fig. 17-10 Container code system that identifies type of plastic.

medical supplies (devices, sterilization packages, clasps, etc.), grocery bags, and bags–in-boxes.

One of the principle methods of reducing the municipal waste stream is called source reduction, a simple reduction in the weight and volume of materials that are typically thrown away. Plastics packaging has been instrumental in achieving this goal of source reduction. A study (conducted by the German Society for Research into the Packaging Industry) of consumer packaging shows what the effect would be if all plastic packaging were replaced with other materials. The weight of waste would increase by 404%, the volume of waste would increase by 256%, the use of energy would increase by 201%, and the cost of packaging would increase 212%.

Velcro for Flexible Packaging

Velcro USA, Manchester, NH, a subsidiary of the European Velcro Group of companies recently introduced a low cost version of its hook-and-loop closure called Touch Seal. It was designed for use in flexible plastic film packages (see Chap. 15, Continuous Injection Molding, Velcro Strips).

Building and Construction

The second largest market for plastics is building and construction, which consumes about 20 wt%. However, the amount of plastics used is only about 5 wt% of all materials consumed in building and construction. Hence this market represents a potentially large growth area for plastics. Given the right economic incentives, the building and construction industry will no doubt find new ways of exploiting their properties of durability, performance, endurance, insulation, and aesthetics. Various plastics and processes are used, including injection molded fixtures (electrical outlets, pipe elbows, etc.), profiles, paneling, insulation, column support, and reinforcing ribs (Fig. 17-11).

Lumber

Recycled plastics such as commingled plastic, polyethylene plastic, and polypropylene plastic can be used as lumber. They are principally extruded; other processes are used such as injection molding, to produce products competitive to wood lumber on land and in the water. For example, boat docks and decks can be made with mixed recycled plastic lumber. Plastic lumber would be maintenance free for at least half a century, as opposed to fifteen years for treated wood and five years for untreated wood. Extensive use is made in applying plastics in wood to improve their structural and decorative properties.

Plastic lumber scored a major commercial breakthrough during 1999 when Home Depot Inc., the world's largest home-improvement retail chain, began to stock products from USA Plastic Lumber Co., Boca Raton, Fl (America's largest maker of recycled plastic lumber, made mostly from HDPE milk jugs and shampoo bottles). The nation's second largest (Loewes) and third largest (Menard) home-improvement retailers also now stock Boca's lumber.

Pallets

In the industrialized countries there are almost more pallets than people. The United States has about 1.6 billion while Europe has at least 0.5 billion. Virtually all are made of wood. Since at least the 1950s various organizations have molded plastic pallets. The major obstacle has been to produce pallets meeting performance at costs competitive to wood. Specialty use has limited their use. Gradually, slight market penetration has occurred, particularly where special requirements exist that favor superior performances and cost advantages of plastics.

A typical plastic pallet weighs about 20 kg (44 lb) and typical sizes are 1.0 m × 1.2 m or 1.1 m × 1.3 m. High density polyethylene plastics are predominantly used. Generally plastic pallets have a 4:1 price disadvantage (wood ones cost is about $17); however, they offer certain advantages. These include

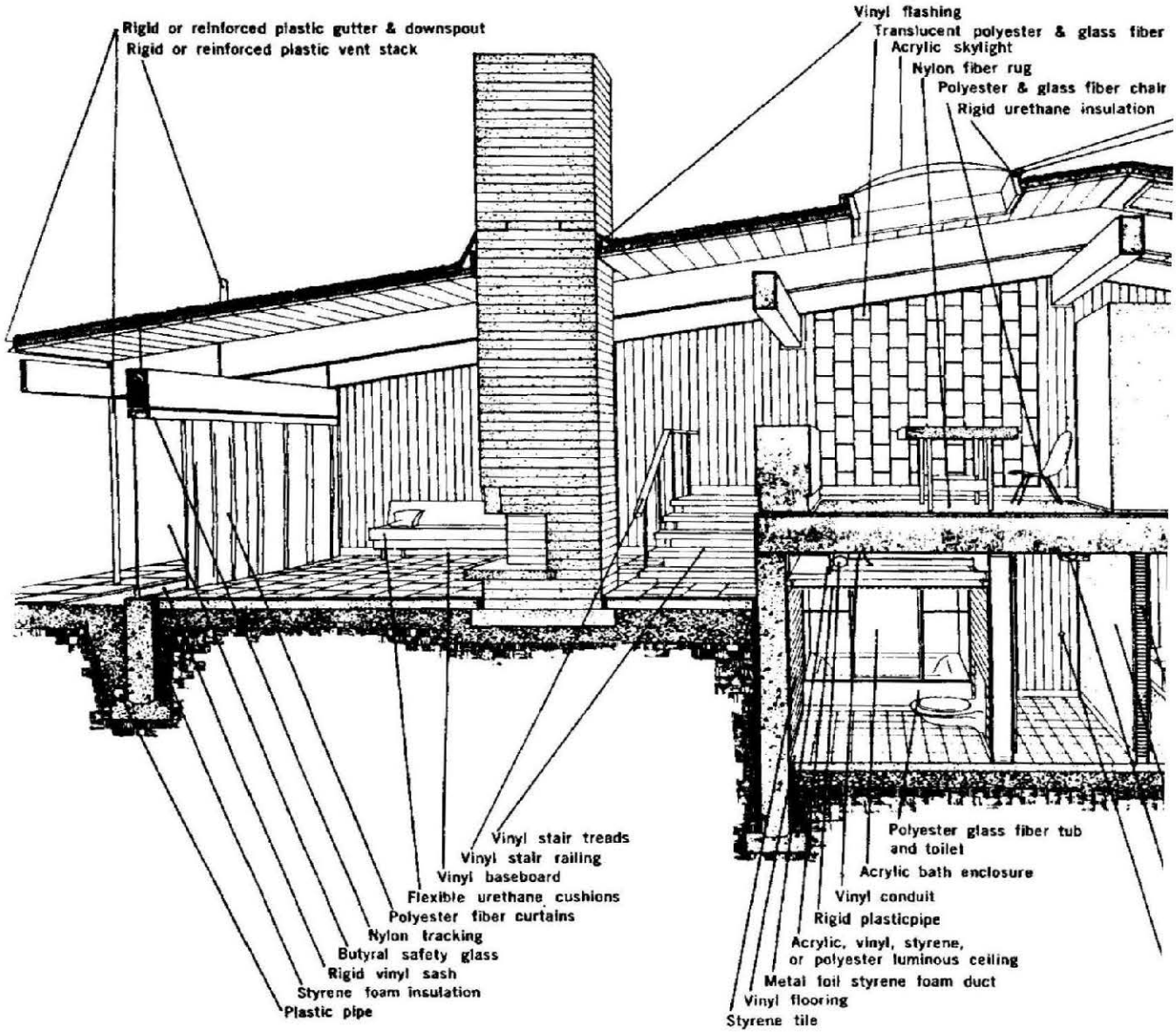
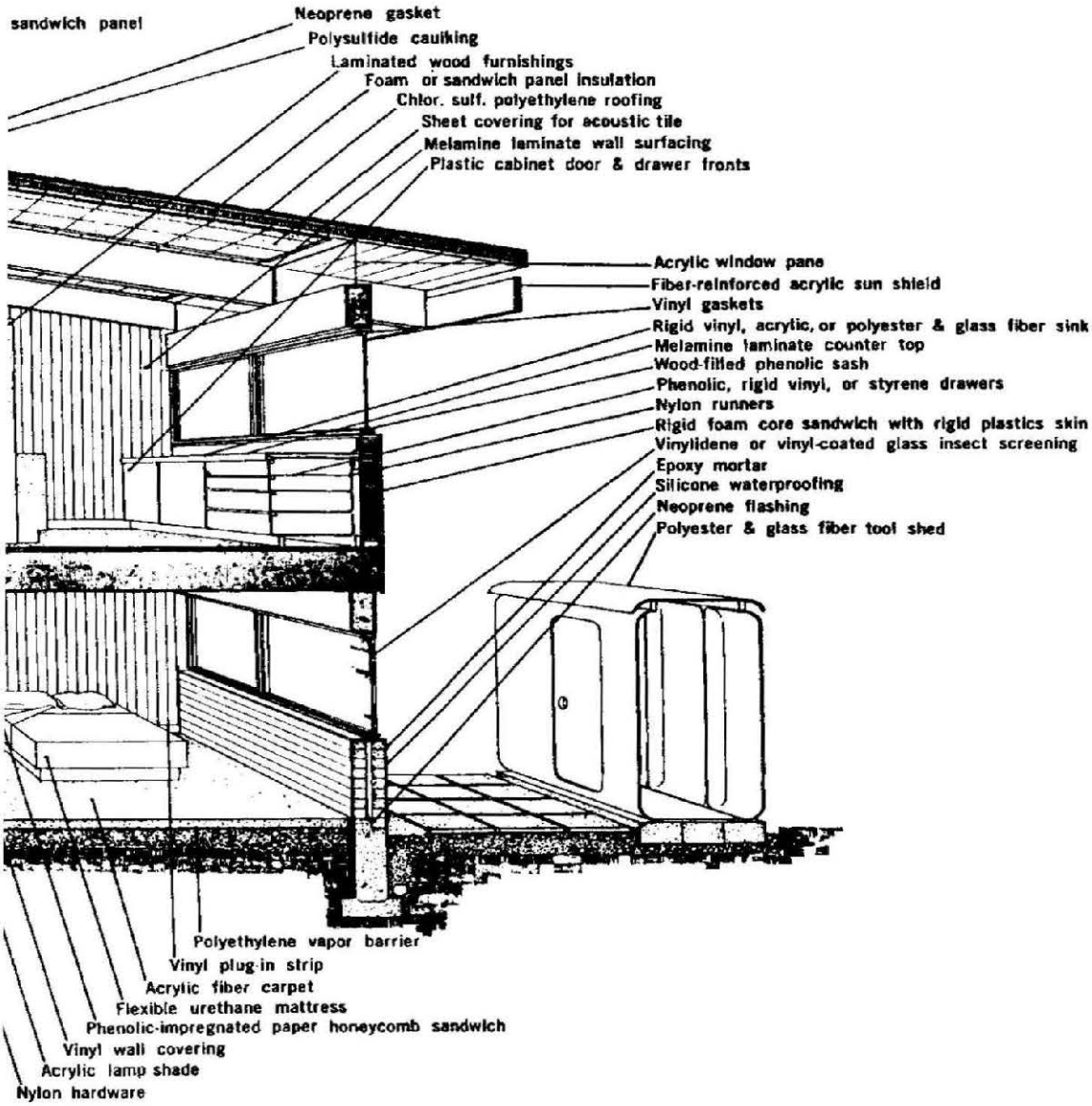


Fig. 17-11 Examples of plastic uses in buildings



that include injection molded products.

savings generated by use of recycled plastics, and long life. Plastic pallets are ideal for closed-loop in-plant shipping, their use minimizes load damage, and they are easy to clean, nestable, chemically inert, moisture proof, harbor no pests, and lack splinters and exposed nails. They help reduce worker injuries, improve plant sanitation, and with fire retardant agent provide fire resistance. With the increasing use of robots, the uniform size and weight of plastic pallets is also advantageous. An important criterion for pallets, which has limited plastics use in the past, concerns taking at least a load of one ton in racking.

Automotive Parts

Long established as the product of choice for auto interiors, plastic over the past couple of decades has also gained favor for use in exterior body supports and panels; Fig. 2-17 is one of many examples. Another example is the front panel shown in Fig. 17-12. Injection-molded products continue to make impressive inroads under the hood; the high

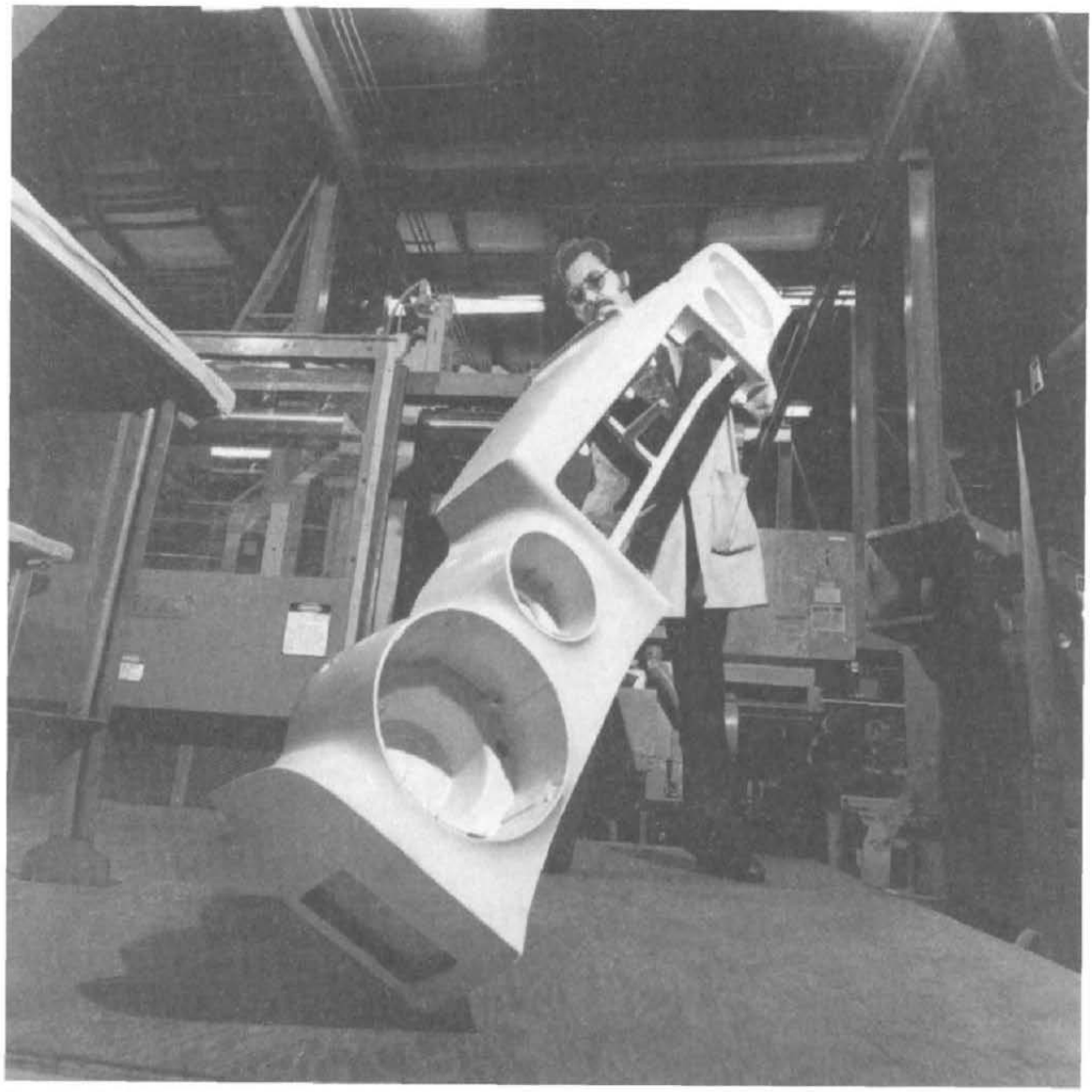


Fig. 17-12 Injection molded auto front panel using glass fiber TS polyester plastic compound resulting in a structure with 30 to 50% weight savings over a comparable metal part. Other advantages include corrosion resistance.

performance of molded parts gives them the potential to replace just about every component in the power train.

Printed Circuit Boards and Surface Mounted Technology

The traditional method of mounting components on printed circuit boards (PCBs) is known as through-hole technology. With through-hole technology the wire leads of components are bent perpendicular and inserted through the PCB molded or drilled holes and then soldered in place. With surface-mount technology (SMT), the leads of the components do not pass through the PCB; instead the leads are bent parallel to the surface of the PCB and soldered to pads on the surface. To create the solder joint, a solder paste is applied to the board using a screen printing or stenciling process. After applying the solder paste, the components are placed on the board followed with heating in an oven to melt the solder and form the joint. SMT components are typically much smaller and lighter than corresponding conventional components, making possible the much higher component densities and smaller product sizes required by portable computers, cellular telephones, and similar devices. Consequently, SMT accounts for over 50% of all PCB manufacturing.

U.S. Postal Service

Molded parts permeate the huge operations of the U.S. Postal Service. These include many different size containers requiring rigid and extensive handling, molded bearings in their many complex mechanisms in sorting and moving mail, intercommunication devices, and parts for small and large trucks.

Medical Applications

A variety of molded products using many different types of plastics are extensively used in medical parts and devices. Examples of just a few products include acrylics for bone replacements, dentures, contact lens, and artificial eyeballs; fluorocarbons for artificial corneas, reconstructive surgery, and bone substitutions; polyamides for vascular implants, clamps, and blood transfusion sets; polycarbonates for syringes, heart–lung machine parts, electrical connectors, and containers (289).

Toilets and Water Conservation

A molded-in TP polyester ribbing component and a mechanical seaming technique play key roles in the innovative design of a pressure tank for water-saving system for toilet flushing. This pressurized system uses only $1\frac{1}{2}$ gal of water per flush versus 5 to 8 gal per commercial system.

Bearings

Self-lubricating molded plastic bearings are used in place of metal bearings in bushings, flanges, thrust shaft configurations, etc. Various plastics, including the popular nylon and acetal plastics, are used to meet different performance requirements. Additives, such as silicone fluid additives, permit or extend the use of certain plastics. Some plastic parts are used as replacements for gauge and needle bearings.

Blow Molding Innovations

Blow-molded products from one extreme to another—tapered to collapsible and corrugated, very simple to very complex shapes—are used extensively in packaging and other markets. Products include blow-molded type bottles, containers, special tubing, and so on (Chaps. 15 and 16).

Annual U.S. sales of blow molding machines are about $300 million; these machines produce about 11 billion lb of plastics. The type of plastics by weight is about 65% HDPE, 22% PET, 6% PVC, 4% PP, 2% LDPE, and 1% others. Marketwise it is about 22% food, 20% beverage, 15% household chemicals, 12% toiletries and cosmetics,

8% health, 7% industrial chemicals, 5% auto, and 11% others. Almost 74% of processes are EBM, almost 25% are IBM, with only about 1% using other techniques such as dip blow molding. About 75% of all IBM products are bioriented.

Beer Bottles

The potential to package beer in bioriented stretched plastic bottles in the United States using coinjection or coextruded plastics such as PET and/or PEN lies on the horizon. Various barrier plastics or systems are used such as EVOH or nylon, coating of LCP to protect taste and extend shelf life, and/or amorphous carbon treatment on internal surface (ACTIS) using gas in its plasma state (89, 123). In the U.S. beer almost went into Coor's acrylonitrile-styrene (AN) plastic stretched blow molded bottles during the 1960s. See Chap. 15, Stretched Blow Molding Operation Specialties and later in this chapter on History, Coor's Beer Bottle and also review History, Coca-Cola Bottle.

Collapsible Squeeze Tubes

Artist John Goffe Rand invented the first (metal) tubes in 1884. They were originally used to hold artist paints. By 1892 the U.S. dental world started using tubes. Later, and particularly more recently, all kinds of products are contained in tubes (perfume, paint, food, adhesives, etc.)

These tubes are usually identified as airtight, collapsible, light, unbreakable, convenient and easy to use, sterilizable, and economical. Extensive use is made of injection molded plastics on the ends of tubes. This is a big business worldwide with plastics comprising about 30 wt% [predominately PE or PP extruded tube bonded to an injection molded cap (Fig. 15-44)], metal (aluminum) comprising 30 wt%, and laminated products (paper, aluminum, with predominately plastic film tape wrap, etc.) supplying the remainder. For containing toothpaste and other products, some of the aluminum tubes must be coated inside with a plastic barrier material to protect the aluminum from certain packaged products; exteriors may be plastic coated to provide special decorations (567).

Asthma Inhalers

On the horizon is a new variety of micromolded inhalers for asthma sufferers (like me since birth). These "soft mist" (IVAM NRW, Dortmund, Germany) inhalers differ from other types in that the mist is created mechanically rather than with CFC-gas propellant. Forcing the medication though a nozzle with channels only a few microns in diameter creates the mist. The nozzles create a slow-moving cloud that can be easily inhaled deep into the lungs (Chap. 15, Micro Injection Molding) (376).

Economic Control of Equipment

Like death and taxes, rising costs are inevitable. Thus the main consideration in investing capital must be the ratio of earnings to costs (Chap. 14). General business factors to consider are reviewed in Figs. 17-13 to 17-15. Production aids can make a considerable contribution to reducing costs. The most important are those required for feeding the raw material, deflashing, regrinding and recycling scrap, sorting the moldings from the sprues, demolding, stacking, packing, automatic machining, and bonding with adhesives (Chap. 10).

The only item that does not rise in cost is the machine performance. There are always new machines that will provide lower cost to melt the plastics.

Factors to be considered in the acquisition of new injection molding machines are the criteria established by the intended production program. For the injection molding of packaging, the main factors are the injection rate, dry cycle time, plastification rate, and price of the machine. In contrast to this, the quality of the melt, process control aspects, and the clamping force are the factors that predominate in the production of machine precision parts.

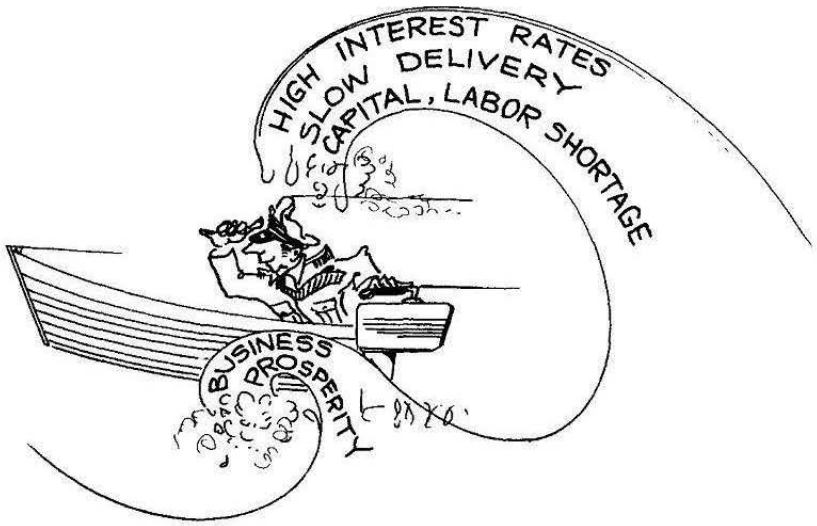


Fig. 17-13 Simplified view of economic efficiency and profitability.

Other requirements that are imposed on an injection molding machine for economic running are favorable start-up characteristics, constant production characteristics, ease of operation, ease of retooling, and a long life.

Savings can be achieved in tooling by standardizing the platens, radii of curvature, fittings, and electrical circuit. Machinery costs can be reduced by parts that do not require maintenance. This applies particularly to the hydraulic system.

Practically any step involved in processing the plastics contributes to cost and can easily be evaluated with respect to cost reduction. Consider, for example, when you should replace your machines, as well as upstream and downstream equipment. Various methods can be used to replace old equipment. In the United States today, many molders are losing money with old equipment, and they do not even know it. Not only are the new machines more productive, they also create less waste, use less energy, and are smaller, quieter, and safer.

Cost savings may also be possible for fresh water and effluents. There is generally

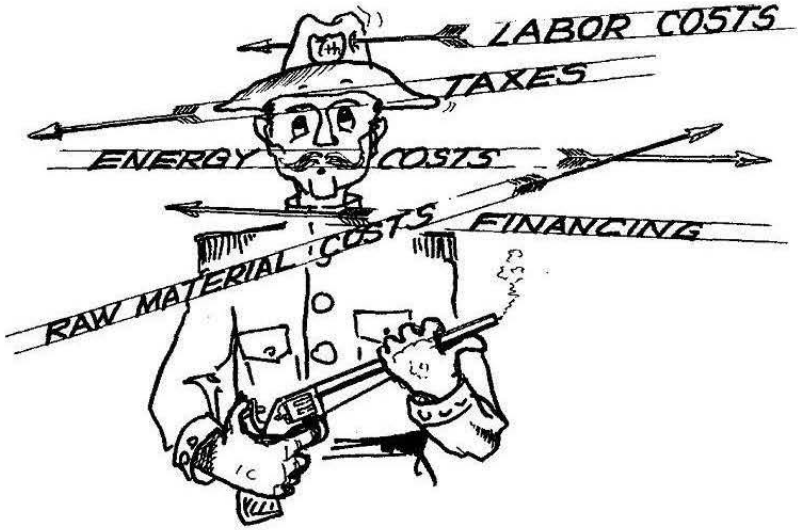


Fig. 17-14 Example of manufacturing costs.

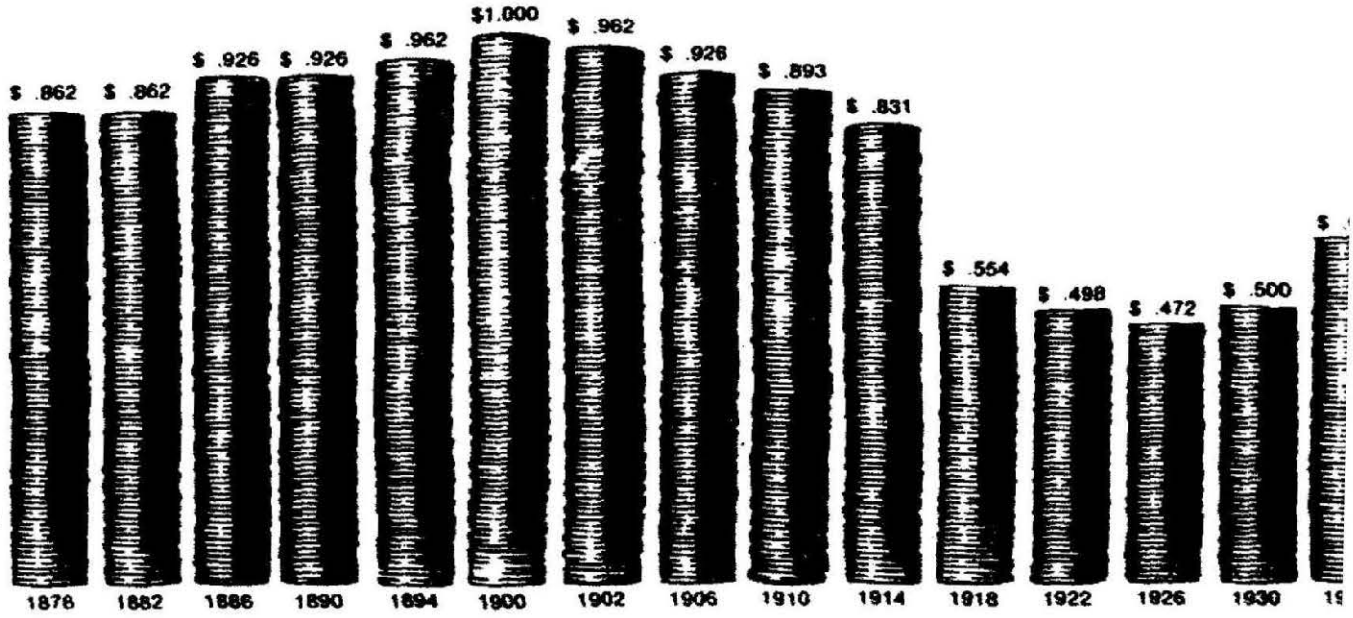


Fig. 17-15 Value of the dollar has an a

symptotic approach to the zero line.

a shortage of water in periods of dry weather, and water consumption in factories is growing as a result of increasing mechanization. Consequently, many injection molding factories have their own cooling water supplies. The main types are: (1) open-circuit water cooling systems with an evaporation-type cooling tower, (2) closed-circuit water cooling systems with compression-type refrigeration machines, and (3) composite systems.

Open-circuit cooling systems operating exclusively with cooling towers were very popular in the past, but they are not the most efficient. As a result of evaporation and slime formation, 1.5 to 2.5% of the water circulated is lost and must be replenished. The temperature and humidity of the ambient air impose limits on the temperature that can be attained by the cooling water. At most, the temperature of the cooling water can be reduced to a value of 3°C above the wet bulb temperature. This is quite unsatisfactory, especially in the summer.

The compressor-type refrigerating machines in the closed-circuit systems operate with air- or water-cooled condensers. Reciprocating machines and turbocompressors predominate. The main refrigerant is liquefied fluorohydrocarbon under pressure.

Combinations of open- and closed-circuit cooling water systems also operate with evaporation-type cooling towers. Normally, the temperature of the cooled water in the closed refrigerating machine circuit is between 5 and 20°C. This water is used for cooling the mold. A second system of pipes carries the water that is cooled by flowing over the cooling tower. This water is used for the condenser of the refrigerating machine and the hydraulic system. The twin-circuit system saves great amounts of energy because it can function as a single-circuit system in winter with the evaporation-type cooling tower. In summer, it is refitted as a twin-circuit system.

Automated Production

As explained, rationalization efforts in the area of mass producing injection molding parts in the past have led to increasingly tight networking of peripheral components (upstream and downstream equipment to the injection molding machine) (62). This applies to removal of parts from the machine with the aid of handling technology, downstream systematic deposit, and also upstream devices that make possible the rapid, automatic exchange of molds and manipulator clamps (Chap. 10).

Because requirements continually have broadened, the injection molding machine itself, has also undergone some far-reaching changes, especially in the facility for automatically making media and power connections between mold and machine. Examples include rapid-clamping systems; automatic ejector coupling; automatic coupling of water, electricity, air, and core-pull oil; automatic adjustment of dimensional and production parameters; automatic safety screens; and automatic material change. Advances in process control, and the facility for electronic interconnection of all component parts by means of ever more powerful controllers, make it possible to construct flexible production islands or complete manufacturing units.

In the course of this development, all components had to undergo somewhat extensive alterations and supplementation—above all electronically. However, individual components have not all reached the same standard during the automation of injection molding, with injection molds being the most deficient by far. This is particularly the case in relation to coordination with the interconnecting components of the system, such as mold-change devices, quick-fit systems, and handling systems, and also for process monitoring, production safety, and automatic start up. The reason for this may be that a mold is, first of all, a device designed individually for the particular purpose of shaping the plastic melt. This objective has, so far, taken priority over the function of the mold as a module in a flexibly equipped plastics processing unit.

Additional improvement may be sought by transforming the role of the toolmaker from simply a mold designer to an active partner in building a logistics system. The tool is not especially important within the automated

system as an end in itself, but more as the environment for melt shaping. Thus, the injection mold must be incorporated into the overall system and coupled to it via interfaces. It must be possible to start production on a given mold automatically, without the individual involvement of operators.

For the injection mold to become a component of an automated production system, besides the usual design criteria (number of cavities, clamping force, cycle time, holding time, etc.), some additional criteria have to be considered. Of particular concern are mechanical interfaces, process-related gating of the tool, and the preconditions necessary for automation.

Energy Savings

Like the plastic output capacity of injection molding machines, the energy efficiency of injection molding machines (and other equipment) is an important consideration. The efficiency of machines depends on factors such as the usual hydraulic pressure used, torque available on the screw, screw rpm, barrel heat control, mold temperature control, and the material being processed. Unfortunately, costly energy losses ranging from 3 to 20% can occur. Energy consumption is a major factor in production costs; it will be even more of a consideration in the future. Machines and equipment are usually overpowered. Although this situation may be better than using underpowered machinery, processes should not waste energy, which results in higher product costs. Information on energy efficiency is reviewed throughout this book, starting in Chap. 1.

Since most of the machines use hydraulic pressure, let us review hydraulic action first. Energy consumption in a molding machine is directly related to the hydraulic pressure used. The higher the pressures are, the more power—and thus the more energy—needed. So the basic approach is to determine how to reduce the pressures required to do the job. Let us explore the possibilities.

First, consider the clamp. The more tonnage that is required to lock up the mold, the higher the hydraulic pressure must be to accomplish this. Whether we are talking about a hydraulic ram machine or toggle machine, the problem is the same.

Basically, we are trying to hold the mold closed against the force of injection to prevent flashing. The first consideration is the mold. Is the mold base relieved to minimize the area of the mold that must be clamped to ensure a good shutoff? This relatively inexpensive adjustment would permit us to use less clamp. Less clamp tonnage translates into less energy used, but it also improves running conditions, as the vents are more effective, etc. So spend a few dollars on the mold to ensure good operating conditions. This sort of periodic expense reduces your monthly expense for power and represents a good tradeoff.

The greatest use of energy occurs at the injection end, where energy is used to produce the melt and force it into the mold. The heater bands draw electrical energy to melt the plastic along with the screw drive, which provides some heat to the plastics through shear (Chap. 3). Putting the plastics into the mold requires high pressures and a large pump capacity. What can we do about this high energy use?

There are quite a few ways to help reduce energy costs in this area. First, consider the screw recovery or plasticating. Probably the most efficient way to run the screw is with about 60 to 70% of the heat being provided by the heater bands and the remaining 30 to 40% by shear. To accomplish this, one needs to know something about the screw and how it works in order to arrive at a heat profile suitable to the resin being processed and the rate at which it is processed.

A starting point would be to set the rear zone of heat at about 50°F above the softening point of the resin to be run, the center zone about 50°F above the front zone, and the front zone at the stock temperature at which one desires to run. Watch the screw drive pressure during recovery. It should be at about 50 to 65% of the maximum available. If it is below 50%, no shear heat is being used, and the mix of the melt is not very good, particularly if coloring is being used. Above

65%, too much of the heat is being entered through shear, a condition that is not energy efficient.

Heater bands are an important possible energy-saving source. Many studies have attempted to analyze reducing energy costs in this area (7). Considerable testing in this area has been conducted, resulting in some sound data on the subject. An example is the testing done with a melt thermocouple in the nozzle to establish a target melt temperature. The only change that we made was in the heat profile, to maintain the target temperature when we changed heater band conditions.

Our standard arrangement used mica heater bands with a 360° cover of shiny aluminum. With this as a base, we then tested without a cover, with insulation fastened to the cover, with ceramic bands and an insulation blanket over the cover, and with the blanket over the ceramic bands themselves.

Removing the heater cover resulted in a 44% increase in energy required. Insulating the inside of the cover resulted in a 12% increase in energy required. Using ceramic bands resulted in a 22% increase in energy required. We then ignored the melt temperature and put the same heat profile on the ceramic heater bands as in the first test. We noted a 10°F (5°C) swing in melt temperature, overriding of the heat controllers in the center and front zones, and a 15% increase in energy.

We found that a heat sink problem occurs, in that the insulation directly on the heater band does not allow for a modulation of the heat at the surface, which is greater than at the thermocouple, so this greater heat has no place to go but down through the steel to the plastic. The full cover with uninsulated bands provides an oven effect that eliminates this condition.

The variation in melt temperature, on amorphous materials particularly, can affect molding conditions to the point of providing slight nonfills or sinks to slight flashing due to viscosity change with the temperature change.

Our recommendation is that uninsulated bands with a full cover be used as the most energy-efficient arrangement, which provides the best control over the melt. Testing of the blanket over the cover is not complete, but this idea would be good for air-conditioned operations.

The force required to put the plastic material into the mold consumes the most energy. Contributors to this problem are the viscosity of the melt, size of the gate, settings of the pressures, and speed of fill, as well as the duration of the boost or delay unload.

The viscosity of the melt must be carefully controlled to obtain the best quality of melt possible. The size of the gate is, however, usually not variable. Gate sizes are usually smaller than necessary because it is easier to open up a gate than it is to make it smaller. Once a mold is filling, the gate size cannot be changed. Although gate marks are an appearance problem on some products, a 0.040-in. (0.1-cm) gate is pretty common in this country and a 1-mm (0.039-in.) gate is common in Europe.

A very small change, in thousandths of an inch, can have significant bearing on the cross-sectional area of the gate. For example, going from a 0.040-in. to 0.050-in. (0.1-cm to .13-cm) gate results in a 56% increase in area. That would have a decided effect on the pressure required to fill the mold. It could also mean a reduction in melt temperature, which translates into faster cycling because less heat needs to be removed from the mold.

So gating has a significant part to play in the energy used. We have not, as an industry, spent enough time considering this factor and the effect it has on part quality, cycle time, and energy consumption.

These are some of the considerations that will affect your operating costs (though not all of them, as space does not permit such an examination).

In conclusion, we can make the following points:

1. Do not try to run a tool that is not in good condition. A few hundred dollars spent on tool maintenance can save thousands of dollars spent on wasted energy.
2. Do not use more clamp than necessary.
3. Learn how to use the screw to the best advantage. Talk to your supplier and get his or her recommendations. Do not use the same

heat profile on different sizes or models of machines.

4. Use as low an injection pressure as possible. Open up gate sizes when possible to reduce the pressure required. Do not hold boost pressure on after the ram stops moving. (Note: Boost or delay unload does not mean pressure, but volume of oil.) Use second-stage instead of first-stage injection pressure.

5. Reduce melt temperature if the gate size will let you. You save energy on melt preparation and on removing it from the mold, while improving cycle time as well.

Management and People

Everyone in the plastics and other industries have the responsibility to ensure that all products produced will be safe and not contaminate the environment. Remember that when you encounter a potential problem, you are often assumed guilty until proven innocent. (Or is it supposed to be the reverse?) Keep the records you need to survive the legal actions that can develop (Chap. 16, Legal Matters). These records, with their development steps including management information, can be very helpful (Fig. 17-16).

Discipline

Bosses or managers strive to achieve balance between group skills and discipline on the one hand and employee individuality on the other. Ideally, one would like to have (1) an organization where people understand the importance of their jobs and are committed to living and operating within the confines of those jobs and to taking directions and (2) an organization where people feel creative and adaptive with the willingness to

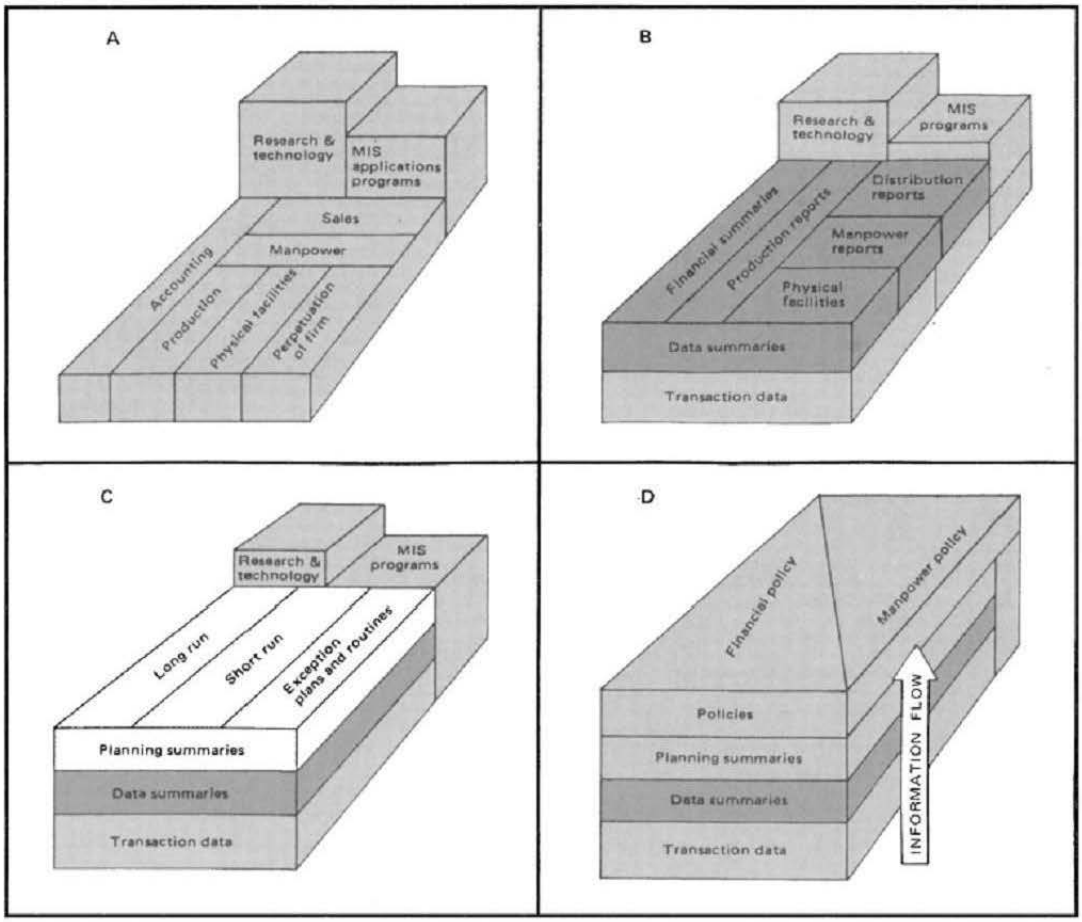


Fig. 17-16 Example of development steps in management information.



Fig. 17-17 Different techniques are used to correct a situation or problem during a meeting; this particular one is not advisable.

change their mind without feeling threatened (Chap. 14, Productivity and People). Unfortunately many working people face situations nearly daily in which they are afforded little respect (Fig. 17-17). To respond with poor performance or lack of participation is not a very helpful attitude. The respect that one desires can only be a result of one's performance and attitude in the workplace. By definition, respect or appreciation is a response to some positive action.

Productivity

The recipe for fabricating productivity includes a list of ingredients. Each has certain limitations depending on factors such as production quantities and product performance requirements interrelated to cost. The ingredients are: (1) research and development, (2) new technologies, (3) updates on equipment, (4) automated systems, (5) modern facilities, (6) certification, and (7) new plastic materials, to name but a few. However, there is one essential ingredient that can bind the recipe together: people. None of the other factors has as much impact without properly trained people. Without qualified people employed in being responsible for the fabricating operation, you are not going to be operating efficiently no matter how large your capital expenditure becomes. Optimizing productivity requires a blend of labor, management, materials science, control engineering, mechanical design, maintenance, and trouble shooting.

Experience

Fabricators as well as other organizations need experienced people to properly conduct any operation. Someone has to know what is needed and how to take the proper control of all the proposals, equipment, tools, software, cost accounting, etc. that are available. One can assume that the bosses, managers, etc. are qualified or can provide the required direction to operate efficiently.

Plant Controls

It is seldom the case that a processing plant has only one processing machine, and if it has more, it is not what happens on the individual machine that determines profitability, but the performance of all machines. With many machines it may become difficult to keep track of all the details (hundreds to thousands) that go into the plant's overall operation. It also becomes increasingly difficult for processors, quality control people, maintenance people, and others always to be available when needed. Moreover it may become difficult for any one individual to make a major decision as needed. Modern central control and management systems have changed this situation.

Plant management systems have been called by different names, including supervisory control, distributed control, CAD, CAM, CAE, CIM, and so on. These different systems can maximize the plant layout efficiency and monitor and control all operating parameters for basic machines as well as all upstream through downstream equipment. The systems receive inputs on all parameters and can issue instructions to each machine to ensure efficient and profitable operation. What is required is someone to establish the settings and instructions for these control and management.

For these systems to operate efficiently, talented people are needed to completely integrate them. These people must be available and must know what is required for all plant operations. They must establish proper start-up through shut-down procedures for

all equipment following a methodology for "threading" the line on start-up. They must build limits into the system control and interface them with the control instructions best suited to keeping the machines' product outputs sufficient to meet performance requirements at the lowest processing cost. Proper training is required to teach personnel how best to operate and set up the equipment and to teach proper adherence to safety procedures.

Analysis of Plastics Affecting Business Strategies

Sooner or later, someone is going to show up with a better product than yours, or one that sells for less that is suspiciously similar to yours. Then the questions invariably start: "Why are *they* having a low failure rate with this product?" "What are *they* making this device out of that allows them to fabricate it so cheaply?" Or worst of all, "How did *they* find out what we use for raw materials, where we get them, and how we blend them?"

Polymer analysis is a definitive science that produces answers to these and other disturbing questions—rapidly, accurately, and routinely.

The following are some examples of puzzles that were easily dispatched by application of some common analytical techniques; some of them are not without humor.

Example 1

After company A had introduced and begun marketing a high-performance specialty polymer for a few years at a premium price, a new company no one had ever heard of showed up with a supposedly similar product for the same market at less than half the price. Terror and gloom rippled through company A.

Efforts to discover the new company's secret were frustrated by the new company's touting a "secret formula," refusing even to patent the new material. Company A prided itself on being progressive and innovative and a few years before had invested in some rudimentary instruments for a small analysis laboratory. A tiny sample of the new material was obtained with no small effort, and the little laboratory was asked one of "the questions."

A solvent was readily found that dissolved the sample. The solution was run through the gel permeation liquid chromatograph and found to be a blend of two polymers differing greatly in molecular weight. The fractions were trapped as they came out of the chromatograph and qualitatively analyzed by evaporating the solvent and placing the resulting films in the infrared absorption spectrophotometer. The two major components were identified in minutes beyond any doubt, though no one at first wanted to believe the answer. With a great deal of hilarity, company A realized they had nothing to fear from the competitor; the new company had reintroduced some 30-year-old technology and was certainly doomed in the marketplace as the shortcomings of its product become apparent. It was humorously easy to see why they guarded their "secret" so well.

The determination of this composition took a little over an hour. Imagine how much marketing retrenching and sudden product redevelopment time were saved.

Example 2

Octopus Chemicals, a colossal corporation, had a division that had manufactured PVC plastisols and a variety of fabric-supported vinyls for many years. The PVC resin was purchased from another equally huge corporation for as long as anyone could remember. All was going very well until Octopus decided to enter the resin business so it could sell itself raw materials, for a number of excellent reasons.

Unfortunately, more than half the first year's production had to be discarded because it seemed impossible to obtain consistent results from day to day. Quality control would report good physical test results, the huge machines would start up and be committed, and as the day wore on, the

physical properties, and even the cure temperatures, of the plastisols would become nonsensical. It became impossible to prepare a formulation whose properties could even be guessed at, and there began to be corporate casualties as Octopus became more and more exasperated with this bungling division, which, in the past, had been profitable and productive.

Finally, someone asked the right question: "What about molecular weight?" Octopus did not have its own GPC facilities, but there was a consulting lab in the area, so a number of tests were initiated. The division insisted the peak and average molecular weights were very similar to those of the material that was formerly purchased from the other corporation. The consulting lab, after a dismayingly short time, agreed.

But they had more to say. In short, a resin with an average molecular weight of 290,000 is not really the same as a blend of two resins, one with a peak molecular weight of 1,400,000 and the other with a peak molecular weight of 2,000! Octopus said, "Well they have the same average molecular weight, don't they?" The consulting lab explained that if a person were to write an unreasonably large overdraft on his or her checkbook, then tried to explain to the bank that the year-long average was enough to cover the check, the results would be similar to what happened to the plastisol.

The right question asked a year earlier, and involving polymer analysis, would have saved enough money to buy many polymer analysis laboratories, and would have saved a few careers as well.

Example 3

A company was in the business of producing medical catheters. In use, these thin flexible tubes were positioned by X-raying the patient; a radio-opaque filler was incorporated into the formulation. To provide the right combination of stiffness for insertion with flexibility for bending easily around corners, the resin was modified by blending an elastomer with another resin. The radio-opaque filler chosen was bismuth trioxide, which was rather expensive but provided excellent radio-opacity.

It was learned that a competitor was charging considerably less for a product that appeared identical, and of course the inevitable question was asked.

A small sample of the competing product was dissolved in chloroform, and the mineral fillers were centrifuged out. The dissolved polymer was separated by GPC, and the fractions were collected and analyzed by infrared absorption spectrophotometry. The identities of the two polymers in the competitor's blend were readily determined. By comparisons of the infrared spectra and running commercial resin samples, even the identity of the suppliers of the resin was found with reasonable certainty, because so few manufacturers were supplying resin to this market. Even so, this did not explain why the product cost so little; their competitor had to be using the expensive bismuth compound because its distinctive yellow color was evident in both products.

An ultraviolet absorption detector was used in the GPC separations, and it was noticed that the detector response was much more sensitive to the competitor's sample, even though great care was used to prepare the dissolved samples at the same dilution as the company's. A suspicion formed, and the centrifuged filler was examined; it was white.

Simple wet analysis showed the filler in the competitive product to be the much less costly barium sulfate. The competitor had added an organic yellow tint to the product so that it mimicked the color of the more expensive bismuth filler! The yellow tint accounted for the strong ultraviolet absorption.

Obviously, the company could have used the cheaper filler in the first place because their competitor's product worked fine.

Even the most abbreviated polymer laboratory, with little more than a liquid chromatograph and an infrared absorption spectrophotometer, can save a company considerable money and anquish by answering questions rapidly and with certainty. Just as quality-control applications of these instrumental techniques can prevent problems before they occur, surveillance of the

marketplace can make tremendous contributions to a competitive edge.

In commercial plastics and resins, as well as many other fields, the days of "secret formulas" are essentially over. There are not many secret formulas that will withstand even 2 h of scrutiny in a reasonably well-equipped instrumental analysis laboratory.

New instruments employ dedicated microprocessors, enormous memory, and rapid data access. It has never been easier to keep track of the marketplace, and, in many instances, it borders on being fun. Product formulation decisions, marketing strategies, and failure analyses can be approached with more awareness and confidence than ever before.

Conclusion: Knowledge is power.

Correcting Misperceptions about Plastics

The issue of credibility for the plastics industry (as well as other industries such as oil, steel, etc.) often arises. There tends to be a lingering misperception that this industry is "bad." If you examine the facts, plastics are and will continue to be one of the best materials ever introduced. Action by different organizations worldwide are educating the public on the advantages of plastics. A typical organization is the American Plastics Council (APC).

There are many ways to examine the facts. One issue is recycling. In the United States, an independent, entrepreneurial industry has evolved to use post-consumer resin (PCR) in ways that maximize its value. This industry is relatively stable and well established with more than 52,000 Americans now employed in the plastics recycling business (Chap. 6, Recycling Facts and Myths). In fact, at last count more than 1,700 businesses were engaged in either handling or reclaiming post-consumer plastics. PCR produced today goes into making more than 1,400 products such as bottles, clothing, timber for landscaping and decking, carpets, and stadium seating. The APC is actively involved in working with industry to both research and promote recycling (1).

Nevertheless, there exists more state-level legislation in the United States pushing for extended manufacturer's responsibility. These proposals would require manufacturers to fund and operate redemption centers for a wide variety of packaging. Proponents of these bills argue that they will increase the amount of material recovered for recycling, but as the European experience has shown, this simply is not the case. Draconian measures such as Germany's Green Dot program increase the regulatory and economic burden on manufacturers while having a negligible impact on recycling rates (214, 222).

Myths and Facts

Imagine our society magically stripped of cost-effective and high-performance plastics. Cars would have missing parts, supermarkets would sell containerless food and cleaning products, there would be fewer medical devices and products, and wires would have no electrical insulation. Indeed, it is difficult to identify any mass-produced product that does not use plastics. Plastics, like electricity and transportation systems, are fundamental to the function of our society.

When machine settings do not properly match the required processing conditions, problems can occur. Unfortunately there are times when myths develop due to factors that range from competition to ignorance. Competition does evolve "at times" among companies, environmentalists, the politicians, the public, and so on. To believe we know something when we have an opinion is a myth (lie). A revealing exercise is to say with every opinion "I do not know but in my opinion . . . ". Any kind of pretense is a myth that can result in people saying "plastics are bad and uncontrollable". When one examines the facts, as contained in this book with its applicable references and other books, it would not make sense to consider such a world without plastics. Plastics are required worldwide; they serve vital functions in communications, medical equipment, and so on. This does not mean that plastics are perfect, despite their goal of asymptotically approaching perfection (Chapter 5, Perfection). Plastics have their drawbacks and unfortunately, like other materials, problems develop when they are not properly designed

or produced (Chap. 6, Recycling Facts and Myths).

The stated mission of Greenpeace organization is to help eliminate worldwide problems. Unfortunately, they have often chosen to "pick" on plastics, without a full knowledge of the facts. For example, Greenpeace ignited the additive phthalates problem (as they put it) in PVC years ago. These additives were used in different products such as toys and medical devices. During 1998 the U.S. Consumer Products Safety Commission (CPSC), while acknowledging it could find no health risks to children from phthalates, recommended that processors stop using phthalate additives in toys. As of June 22, 1999 a long-awaited study from former U.S. Surgeon General C. Everett Koop found that phthalates are completely safe in vinyl medical devices and toys (190, 566).

Improvements in plastic properties continue to be made, expanding our capability to produce products that meet varied performance requirements and reduce costs. In the mean time there are factual and mythical problems. The types of problems vary. Opponents of plastics point to the fact that plastics are made from petroleum, a nonrenewable resource. Most of the plastics familiar to consumers are manufactured from ethylene. During the distillation of petroleum, the ethylene fraction comes off as a by-product, which many years ago was just burned since it was waste. This waste gas became the building block for most plastics. Reports show that in the United States from 2 to 3% of all total annual petroleum production is consumed by the plastics industry. For the record other feedstock materials are used in different parts of the world (vegetation, etc.); however, petroleum is primarily used.

Limited Oil Resources

The words were spoken that "oil was a temporary and vanishing phenomenon, one which young men will live to see it come to its natural end." So it was said in 1885 by a U.S. government official in Pennsylvania (where oil was "born" thirty years earlier). In 1919 a U.S. government official stated "within the next two to five years, the USA oil fields would reach their maximum production." Experts in the 1940s again cautioned that the end of American production was in sight. And during the energy crisis of the 1970s, much of the rationale for government controls was based on the premise that there were no new supplies of oil and natural gas to be found. To put it mildly, events have proved these predictions grossly wrong, as was predicted by many during these demised periods. Often unheard were those who reported what really was happening based on new technological developments.

Limited U.S. Steel Resources

In 1938 it was predicted that U.S. iron ore bodies in the Lake Superior district would be exhausted in the early 1970s. It did not occur because, as usual, new technologies were developed.

Plastic Advocates

Consider being an advocate for plastics. It is not something one becomes once every two years when there's a summit. It is an everyday commitment. But above all else, keep in mind that being an advocate for plastics does not mean knowing all the answers. No one in our industry can safely claim to be an expert on every issue affecting plastics. For this reason, we all need to learn how to comfortably say: "You know, I don't think you are right about that. Let me look into that and get back to you." The American Plastics Council and other organizations are ready and willing to help the plastics industry become effective advocates. Their website is listed in Appendix 4, along with a few of the many organizations that can provide information and service (1).

Solid Waste Problem and Product Design Solutions

The waste-management problems of the United States and the rest of the world continually threaten to reach crisis proportions. Industrialized countries have generated a

Table 17-2 Estimated contributors to solid waste[a]

Percent by Weight	Waste Material	Percent by Volume
37	Paper[b]	40
18	Yard	18
10	Metal	2
9	Glass	3
8	Food	8
7	Plastic	9–12[c]
11	Others	13

[a] Total annual solid U.S. waste is estimated to be more than 300 billion lb (136 billion kg).
[b] Includes, by volume, 12% in packaging, 12% in newspaper, 4% in cardboard, 2% in magazine, and 10% in others.
[c] By some reports, up to 16%.
Note: Seven percent of 300 billion lb is 21 billion lb of plastics. Annual U.S. plastics consumption is about 67 billion lb (30 billion kg), with domestic products at about 61 billion lb (28 billion kg) [including about 33%, or 20 billion lb (9 billion kg), in packaging] and imported products at about 6 billion lb (2.7 billion kg) (contained in electronics, autos, appliances, packaging, medical products, etc.). Waste, like computer programming and nuclear physics, tends to be a subject shrouded in mystery and reportedly understood by only the few. The annual U.S. control and service environment business is estimated at $80 billion, or larger than the total computer business of all hardware and software, plus the telecommunications and airline businesses.

lot of garbage for a long time, but now they are rapidly running out of environmentally acceptable landfills. Unfortunately, this problem expands with the world population. At present, more than 2 billion lb of solid waste are pouring into waste streams annually worldwide (16).

There is no single, simple answer to this problem. Different, limited approaches have been used successfully, and much more action has begun occurring here and internationally to integrate environmentally secure landfills, recycling, advanced waste-to-energy incineration, degradability, product design, waste-source reduction, industry support, public education and support, regulation support, and various economic considerations. We now should stop merely living with past problems and start solving them. Waste is a widespread, but solvable, problem; there is an abundance of possible cures and fixes, some good, others not so good. There are nevertheless logical approaches and facilities to check their reliability.

This overview includes information and positive actions now being taken to provide solutions that will affect all materials. Because plastics usually receive the biggest emphasis, they are the main focus here. Plastics as well as other materials must all definitely be seen as problems (see Table 17-2). Practically all plastics can be made recyclable, incinerable, or degradable, but the conflict of product-performance requirements against economics in most past applications has prevented these factors from being viable. Actions have thus been taken by the plastics industry here and abroad to make positive steps toward helping to reduce plastics waste by recycling, incineration, etc. (Table 17-3).

Unfortunately, generalizations that "plastics are bad" and "burning plastics always generates toxic products" are too often heard from customers and media representatives. More unfortunately, plastics packaging is a highly visible element in the waste stream. And the negative public perceptions about plastics sometimes lead to negative opinions about the companies that use them. These companies must then respond to consumer opinions to maintain their reputations.

The plastics industry has fallen victim to an unrelenting international smear campaign, conducted by certain environmental groups, particularly in the United States. Discriminatory measures have been taken in a number of countries against plastic packaging, although scientific investigations have proven

Table 17-3 Estimated disposition of U.S. plastics used for packaging

	Percentages by Weight			
Year	Landfills	Recycling	Incineration	Biodegradation
1987	96.1	1	3	0
1992	66.5	28	5	0.5
1997	46	44	8	2
2002	37	43	18	2

Year	Estimated Weight of Total Solid Plastic Waste in U.S. due to Packaging
1987	6.8 billion kg
1992	9.1 billion kg
1997	11.3 billion kg
2002	15.4 billion kg

that certain products, in fact, have nothing to do with the rise in the amount of domestic refuse (4). Meanwhile, the demand for plastics products among consumers, who readily appreciate the advantages of this material in day-to-day living, has risen so much that there is now a distinct possibility of disposal bottlenecks arising.

The throwaway aspect, particularly with regard to fast-food packaging, of today's society has resulted in what has been billed in the press and by legislative bodies as the nation's solid-waste crisis. Ironically, in many modern composite landfills, a high-density polyethylene (HDPE) liner is used to reinforce the conventional clay layers, as a way of minimizing leaching. The matter has become a crisis simply because many cities are facing the dilemma of how to dispose of their municipal waste. Many municipalities have filled existing landfills and establishing new ones is becoming more and more difficult.

The plastics industry's response has been to commit itself even more firmly to recycling and to reaffirm its earlier position that waste-to-energy incineration is critical.

Statistics: Fact and Fiction

There is no shortage of statistics about the growing municipal-solid-waste (MSW) disposal problem (seen in Table 17-2), as well as the amount and types of waste materials. Because plastics are lightweight, they translate from a rather low percentage weightwise to a large percentage by volume. Every leading study has shown that plastics make up a smaller share of solid waste than do paper and other materials. Still, in spite of the facts, the public and legislatures continue to identify plastics as the major MSW offender. The result has been a growing proliferation of laws banning or limiting the use of plastic products.

There exist generally held perceptions that the disposal of plastic wastes in landfills or incinerators is harmful to the environment and human health and that the environment and human health would somehow benefit if plastics were eliminated from the MSW stream. Many researchers have determined that these phobias are unwarranted, because plastics cause little pollution of either land or air and are among the most readily combustible components in an incinerator. Whenever a specific plastic poses a potential pollution or other type of hazard, there are procedures available for properly and safely disposing of them.

Another reason why plastics' role in the MSW problem is highly overrated is that they are durable materials that resist the effects of exposure to the elements. The fact that

most plastics are not biodegradable may not sit well with many people, but it still does not change the percentages in Table 17-2 or the MSW stream.

It has been reported that the United States recycles only about 10% of all its waste, incinerates about 13%, and assigns the remainder to landfills. Japan recycles 50%, incinerates 34%, and landfills 16%. Western Europe recycles some 30% and has large-scale waste-to-energy incineration. These other countries have had to take earlier action, since they literally have no landfill areas in the way the United States does.

Landfill

Fortunately, in the United States, as compared to other industrialized countries, municipal landfills can play a bigger role. They will continue to be needed at least for nonrecyclables and the ash from incinerators. They will no doubt be required to operate so that they are environmentally sound and meet all applicable regulations. Unfortunately, many former or existing sites are irresponsibly run and national and worldwide disgraces. Only some 15% of these old landfills are lined to restrict contamination by leaching into the surrounding area.

Recycling

Recycling of waste has become an important approach and a profitable business for some. It so happens that, technically, plastics can be one of the easiest materials to recycle, but economically this tends not to make sense. This is because of the present high cost of collecting, sorting, and processing plastics and other materials. Making any recycling system work requires public, industry, and local, state, and federal support. Fortunately, recycling efforts are on the increase, with more than 5,500 curbside recycling collection programs under way and expanding nationwide.

Business opportunities are gradually developing to produce many different products from recycled plastics, including detergent bottles, office equipment, highway barriers, wastebaskets, pallet strapping, toolboxes, fast-food trays, wetland walkways, signs, hampers, boat docks, park benches, carpeting, irrigation pipes, and many others.

As shown in Fig. 6-54, Goodyear had a two-piece suit and matching tie made from recycled injection stretch blow-molded 2-L polyethylene terephthlate (PET) beverage bottles in 1978. In 1990 it was donated to the new Ripley's Believe It or Not Museum in Wisconsin Dells, WI. The Goodyear recycling process developed shreds bottles into small flakes that can then be processed into reusable polyester plastic. The suit was made to demonstrate the versatility of recycled PET.

Incineration

Incineration solves several solid-waste disposal problems. Done properly, it can reduce the volume of solid waste by at least 90%. And waste-to-energy plants provide a reduction in disposal costs. Adding high-energy plastics of some sort in the waste significantly increases the ease of incinerating the other materials and provide a higher waste-to-energy economic value for the plant's operating costs. Plastics have the highest stored energy value of any material and also the lowest energy cost to produce and process into products.

Most plastics burn cleanly, producing emissions of carbon dioxide, nitrogen oxides, and water vapor, but some produce unwanted by-products such as the vinyl chloride monomer from polyvinyl chloride (PVC). However, PVC and other such by-products can be safely burned at high temperatures of 980 to 1,650°C (1,800 to 3,000°F), using controlled oxygen input, sufficient cycle (residence) time, typically $\frac{1}{2}$ to 2 min, and appropriate auxiliary equipment such as scrubbers and solid salts. However, most U.S. incinerators operate below 870°C (1,600°F) and use only limited auxiliary equipment. For example, incinerated PVC generates undesirable chlorine (and bleached paper much more

chlorine). Exhaust scrubber systems must be used to remove this chlorine.

Degradable

After a long period of continuing successes at improving plastics' durability, there is now more emphasis on using degradable plastics. As is generally recognized, plastics do not readily degrade. Some of the methods used to enhance its degradability include UV exposure (with appropriate additives), bacteria or enzymes (with additives such as starch to aid the microorganisms), and dissolution in water.

Degradable plastics have caused more public controversy than other approaches to providing a meaningful solution to MSW problems. Using degradables is definitely not an overall solution, but it does have some potentially useful applications such as trash bags and particularly mulch films. Degradability unfortunately conflicts with recycling, and there is not enough known yet about the products of degradation.

Analyze Failures

Putting one's failures under the microscope of an objective critique, can often reveal insight into the underlying cause of the failure. You may not want or need to schedule a full-scale inquest every time. But even a quick postmortem on a project that has foundered may keep you from botching another one.

Here are some areas to cover and some questions to ask.

Scope Were you overly ambitious in establishing your original goals for the project? Should you perhaps have lowered your sights in terms of financial or other targets? Maybe the way you expressed your goals was inappropriate. Would it have been better to set a percentage-of-purchase-dollars target for example, rather than a flat dollar figure? Or vice versa?

Money Was the project sufficiently funded, with budgeted money actually available when needed? It is often necessary to spend money to make money. That truism is not limited to hardware or tooling; it also applies to promotional efforts such as vendor days when you invite suppliers in en masse. You cannot run such programs on the cheap side. Vendors may not expect red-carpet treatment at such affairs, but you cannot treat them like carpetbaggers either.

People Were the right in-house staffers assigned to your project? How much say did you have in selecting them? What changes would you make if you had to do it all over again? *Tip*: Remember that those who have shared the experience of failing with you may have learned something from it also. Perhaps they should be exactly the ones to try again with you. For starters, find out if they are critiquing the failed project just as you are.

Vendors Was the right supplier assigned to the effort? Did they know exactly what was expected of them—whether taking on a new commodity or providing technical troubleshooting to users? Sure, parceling out business and assignments to suppliers is what the buying job is all about. But it often takes on a special meaning when a particular exercise fizzles. *Key question*: Does the supplier know that it fizzled?

Structure Was the original project overly complicated? Did its success hinge on too many intangibles and imponderables all meshing like precision gears? Remember the value analysis principle of "simplification" (the KISS approach). Unwieldy programs often collapse of their own weight.

Timing Was the timing right? This means the whole "climate" surrounding the project: the environment of people, systems, business conditions, etc. Even an excellent idea can fail if it falls on barren or rocky ground. For example, it might not be a good plan to introduce a new method for handling rush or small orders, during a period of many new hirings at the shop level.

Information Were the data with which you worked accurate, timely, and valid? How

recently were they gathered? Were they gathered especially for your project? Do you now consider this a plus or minus? Be aware that data pulled together just for one project may be recent, but they could be biased toward the hoped-for result of the project, which makes them less accurate.

Salvaging Should an attempt be made to salvage something from a wrecked plan? Are there successful portions of an overall failure that can be lifted out and applied somewhere? Or should you go back to square one and start all over? Will the eventual benefit of success be worth doing this?

Graphics Would it be helpful to chart the course of the project? This can be a big help when a failed system is under analysis. It helps you identify problems along the line. This kind of graphic treatment can also be used on less methods-oriented programs. If nothing else, you can indicate dates along a charted axis and identify time periods in which things started to go wrong.

Comparisons What makes this particular failure different from a previous success? For the best results, this kind of comparison has to pair objects in the same general area, of course.

Motivation Who else could help sell—or resell—this idea or plan? Again, would it be worth it? Take a figurative look in the mirror and ask yourself one more question: "Would I buy a used idea from him or her?"

Using failure to be successful Believe it or not, it can be beneficial to plan failure. Thus, you can gradually improve the product so that the minimum cost is applicable to molding parts.

Creativity

The creative process involves synthesizing information so that new and useful insights can be achieved. Plastics provide many different opportunities for creative people. See the example in Chap. 4, Correcting Mold-Filling Imbalances in Geometrically Balanced Runner Systems.

To find unique and creative solutions to difficult challenges (which were not resolved by past tried and true techniques) one must rid oneself of frustration and negative attitudes. Problem solving in designing and fabricating through to production, like with business and personnel problems, generally requires a creative yet systematic approach. If practical, rather small changes should be made and time allotted to monitor the reaction or result. Having limited patience or lacking persistence tends to invite unimaginative suggestions and attempts to only use "past approaches."

However, when the problem is particularly difficult or limited time exists, consider a new and imaginative approach using techniques that classically generate creative ideas. Brainstorm as many ideas as possible, even those remotely related to the problem. During the idea generating phase, it is of critical importance to be totally positive. No ideas are bad. Evaluation comes at a later time so do not attempt to provide creativity and evaluation at the same time. It could be damaging to your creative approach. Seek quantity of ideas, not quality, at this point. All ideas are good with the best becoming obvious later.

If possible relate the problem to another situation and look for a similar solution. This approach can stimulate creative thinking toward other ideas. Try humor; do not be afraid to appear ridiculous. It is better than becoming upset or crying.

The next step is to evaluate all the ideas. Consider categorizing the list. Add new thoughts, select the best, and try them. If after going through this process nothing satisfactory occurs, rather than give up, look for that real creative solution. It is out there. You may be too close to the problem. Get away from the trees and look at the forest. Climb up one of the tall trees and look at what has happened from a different perspective.

Use your creative talents, but again, be positive, for a positive attitude brings success. You have creatively worked through the frustration and negativism that problems seem to generate. Your increasingly creative input will generate future opportunities. Rather

than use the approach that "my mind is made up so do not give me the facts," recognize that there is always room for improvements.

Innovations and the Markets

Related to creativity is innovation, the process of fusing knowledge to construct, position, and deliver new product needs to the market. In the plastics industry innovations from plastic materials to equipment to designs are required to be competitive and remain in a profitable business producing injection molded products (526).

Work smarter Just as the computer is a superior control and filing device, it is also a management tool. Even today, the more sophisticated captive and custom molders rely on their multicolor CRT screens and daily computer-generated management reports to check the pulse of their business. The leaders of the industry are so busy today that they could not possibly work any harder. They have to work smarter. Thus, they will increasingly rely on the computer to provide them with the information they need to intelligently settle the disposition of manpower, machines, and materials. They will let the product designers worry about part design, the plant engineers and machinery builders be concerned about science, the production people see about molding the part, etc., while they run the business.

Today, such people are seen as innovators. They are busy further automating their plants, in some cases integrating molding with the entire manufacturing operation. They are looking for ways to improve molding quality by controlling temperature and humidity in their buildings and saving energy by using the heat that escapes from the molding process.

Industrial Designers

Industrial designers provide the professional service of creating and developing concepts and specifications that optimize the function, value, and appearance of products and systems for the mutual benefit of both the user and fabricator. Creative concepts and specifications are developed through collection, analysis, and synthesis of data guided by the special requirements of the customer or fabricator. Industrial designers are trained to prepare clear and concise recommendations through drawings, model, and/or verbal descriptions while observing ethical business practices (163).

The unique contribution of industrial designers is to provide a practical concern for technical processes and requirements for product fabrication and economic restraints. Design recommendations utilize materials and technology effectively that comply with legal and regulatory requirements (Chap. 16, Legal Matters). Designers supply concepts for product identities, advertising devices and packaging, exhibit designs, etc.

Industrial design services are often provided within the context of cooperative working relationships with other members of a development group. Typical groups include specialists in management, marketing, engineering, and fabricating. Education and experience are usually required in anticipating psychological, physiological, and/or sociological factors that influence and are perceived by the user are essential industrial design resources.

Da Vinci's Creativity

An example from the past is Leonardo Da Vinci's creativity with his different machine designs. In an elaborate paper, read in London before the Newcomen Society and focusing on an interesting detail theorizing on matters related to engineering, attention was called to the difficulty of deciphering his manuscripts with its many ideas on account of the peculiarity of his writings. The following particulars were noted. He wrote from right to left after the fashion of the Semitic group of languages. His writing was of the kind known as mirrored or reversed, such as what would be produced by looking at a manuscript through a mirror. He employed an elaborate scheme of abbreviations, and



OR

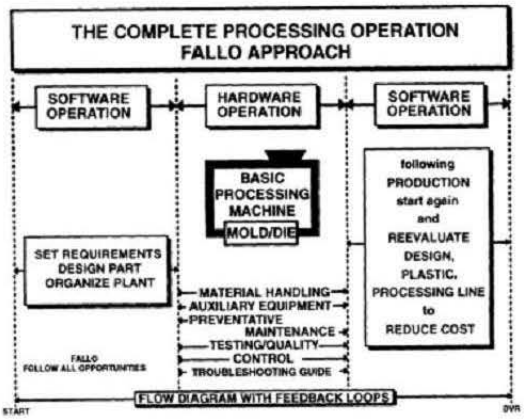


Fig. 17-18 Target for zero defects the proper way.

he omitted the use of punctuation (178). Da Vinci's creative genius would be well put to use in the contempory plastics industry.

Design Successes

In the past the reputation of plastics periodically has been tarnished by the designers and engineers who, having decided to introduce a new plastic product, lavishly copied the metal part it is supposed to replace. Too much emphasis cannot be placed on the general principle that if plastics are to be used with maximum advantage and with minimum risk of failure, one must take advantage of their characteristics and behaviors (Chap. 4). It is essential for the designer with limited knowledge in working with plastics to do some homework and become familiar and keep up to date with plastic processes and materials. Figure 5-1 provides a simplified summation of what is required; the details are reviewed in the table of contents of this book.

Target for Zero Defects

As reviewed throughout this book, the ultimate performance for any processor in terms of quality or producing a product to meet designed performance requirements at the lowest cost is zero defects. This is unlikely to be achieved by the usual quality control procedures since QC analysis is usually only undertaken "after production" and inherently is based on the acceptance of a certain level of failures (Chap. 12).

Therefore, if a quality standard is to be really effective, it must start earlier than any investigation that may occur haphazardly in the production shop (Fig. 17-18). Everyone from the top management strata to production people must think in terms of quality and realize that any acceptance of a second best attitude is not permissible. Proper quality control leads to on time delivery of products and provides increased profits (Fig. 17-19).

Excess Information: So What's New?

Reports indicate that the global information technology market, at about $600 billion/year, is burying us in facts. An independent, international survey (of 13,000 managers) published by Reuters Business Information suggests that an excess of information is strangling business and causing personnel to suffer mental anguish and

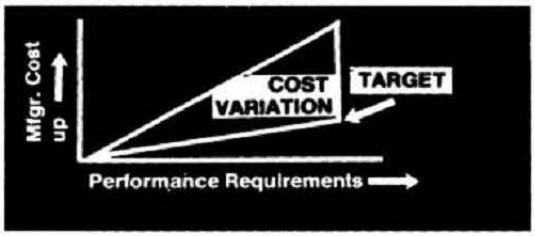


Fig. 17-19 Schematic approach to ensuring profitable ventures.

physical illness. There were those that stated they needed the information to perform effectively. Almost half predicted that the internet would play a primary role in exacerbating the problem in a couple of years. Important decisions are delayed and the ability to make decisions is affected as a result of having too much information (149).

It is interesting to relate this problem to the attempts at solving the myriad societal problems by our politicians and do-gooders. The usual proposed solution involves providing more education to eliminate the problems that develop. But despite the billions of dollars spent on education, major societal problems persist (e.g., medical cost containment, environmental management, educational infrastructure challenges). Fortunately, in the business world, such as in injection molding operations, companies have to survive and be profitable, and so human logic is used. Continuing educational developments are needed in the world of plastics and these are logic driven. However, it is essential for one to obtain reliable information by sifting through all the relevant and irrelevant material available. (Chap. 1, Training Programs; Chap. 2, Molding Operation Training Program; Chap. 9, Computerized Software and Database Programs; Chap. 12, Training and People).

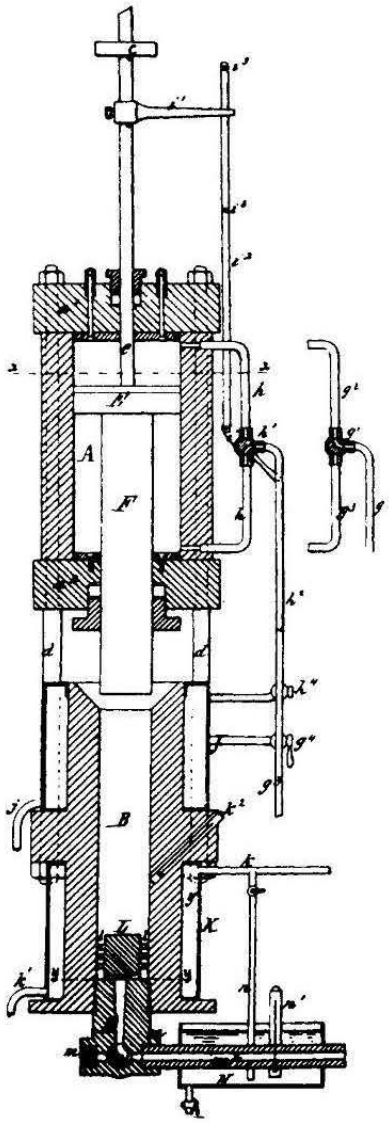


Fig. 17-20 First U.S. patent for molding (1872).

Fabricating Employment

In the United States the yearly man hours employed in producing plastic products by all processes is estimated at 650 million, second to motor vehicles at 845 million. Following plastic products (in millions) are aircraft at 570, commercial printing at 560, newspapers at 475, meat at 460, metal structural products at 350, and computers at 325. The U.S. plastics industry is growing and creating jobs faster than any other manufacturing sector (1, 541).

History

Injection molding machines for plastics were derived from metal working or die-casting machines. In 1872 the first U.S. patent was issued to John Hyatt for a machine called a stuffing plunger IMM, which processed principally thermoset plastics (Fig. 17-20). Designs have evolved considerably since that time, utilizing the basic principle of melting plastic and forcing it into the cavity of the mold. They range from the ram to screw plasticizers (Chap. 2).

Many other developments have occurred worldwide. For example, during 1920 in Germany the first of the modern thermoplastics were injection-molded and during 1927 pneumatic jacks were used to provide higher injection pressure. HPM of the United States introduced their IMMs during 1931 (Fig. 17-21). Italy in 1939 produced self-contained

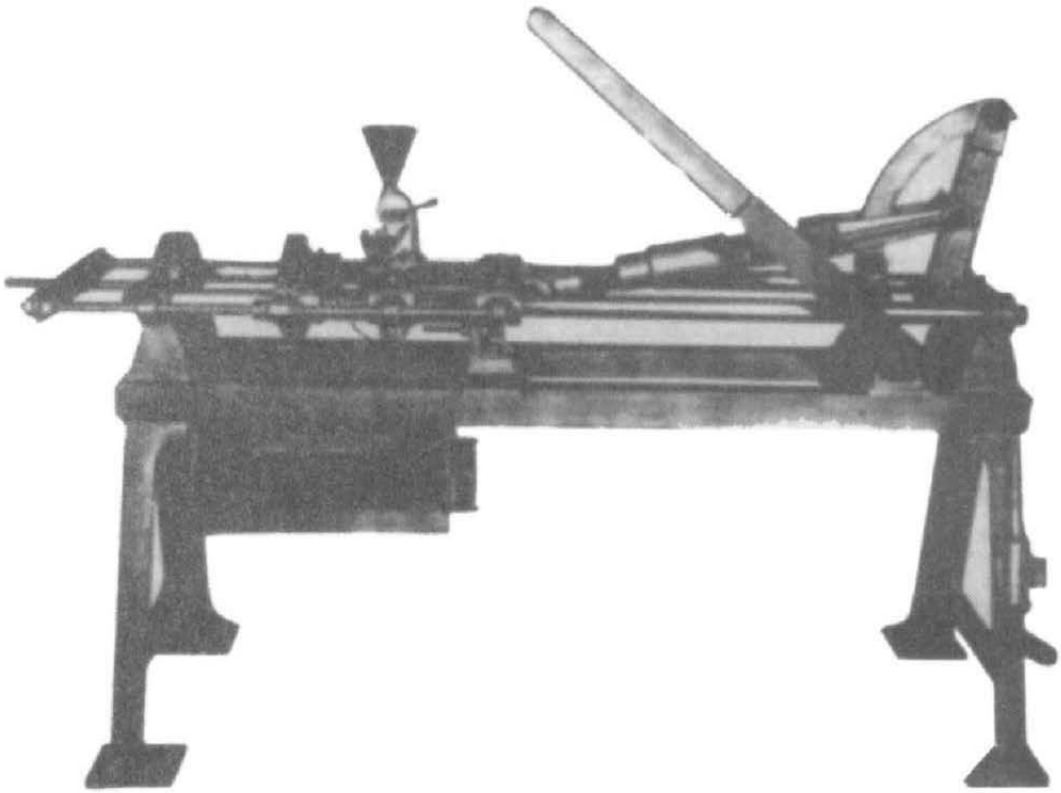


Fig. 17-21 HPM IMM built during 1931.

hydraulically operated IMMs. Highlighting a more recent development was the first inline, single-stage-reciprocating screw, invented by William H. Willert in 1951, with Reed-Prentice in 1953 building the first single-stage-reciprocating IMM. Its patent 2,743,226 was issued on February 14, 1956 (Fig. 17-22) (76, 113, 144, 235, 311, 358, 365, 372, 377, 397, 472, 457, 490, 510).

Only a few additional historical events are to be reviewed.

John W. Hyatt (printer), 1837–1920 In 1868 the first commercial U.S. plastic was produced. It was cellulose nitrite made by mixing of pyroxylin and nitric acid with camphor. It was developed as a substitute for ivory in billiard balls and earned Hyatt a $10,000 award from a billiard ball manufacturer.

Leo Hendrik Baekeland (inventor), 1863–1944 Born in Ghent, Belgium, Baekeland did early work in photographic chemistry and invented Velox paper (1893). Later, while in the United States, he discovered phenol-formaldehyde plastic originally called Bakelite (1909). Although the reaction of phenol and formaldehyde had been investigated by Bayer in 1872, Baekeland was the first to learn how to control it to yield dependable results on a commercial scale. The Baekelite Co. was founded in 1910; it later became a division of Union Carbide and continued to change ownership.

Barrel History

The original barrels used over a century ago were for extruding natural rubber. They were nitrided steel or special steel alloys and of one-piece design with a very high chromium content. Since that time the trend continues toward bimetallic barrels. Industrial Research Laboratory developed the first bimetallic barrel in 1939. The product was called Xaloy 100. It was a centrifugal casting and had an abrasion resistant liner material inside an alloy steel outer shell. These bimetallic liners were originally used

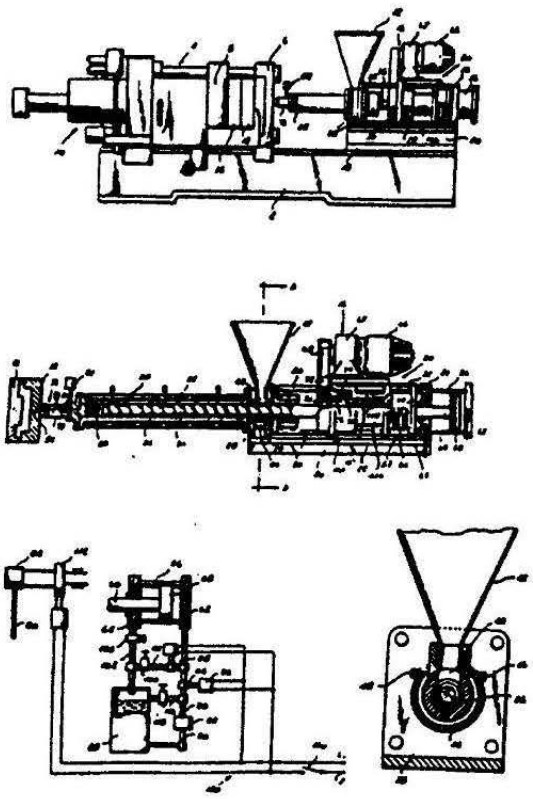


Fig. 17-22 W. H. Willert reciprocating screw plasticator patent issued 1953.

as mud pump liners in the oil fields and later became available from different sources worldwide.

Hopper Magnet

When preparing plastic materials and compounds extreme care is taken to prevent contamination. As a final check, magnetic devices in different rod configurations are placed in hoppers to remove any residual magnetic material.

Blow Molding

Blow molding of thermoplastics is now in its second century. The first U.S. patent was filed by the Celluloid Manufacturing Company of New York May 22, 1880 with an issuing date of February 1, 1881. A fabricated cellulose nitrate plastic tube was produced prior to being heated and blown. Later this tube was identified as a parison. A ram extruder was used to fabricate the tubular shape sheet that was bonded along a scarf joint. Other methods to form the parison included the preparation of a high viscosity lacquer solution used to overcoat a mandrel. Vials and other containers were produced by these and other original concepts (Chaps. 15 and 16, Blow Molding).

Major new developments occurred in blow molding during the 1920s and 1930s with the advent of extrudable cellulose acetate, ethyl cellulose, polystyrene, acrylic, and, most importantly, polyvinyl chloride. With the castable plastics, the dip-coating of parisons became popular. Composite materials (made in a manner similar to our present coextrusion techniques) were also used. These included PVC adhesively bonded to pearlescent cellulose nitrate.

By the late 1930s, major new developments involved the use of a controlled parison softening rate and relating the temperature profile to improving blow molding efficiencies. Prior technology involved basically the extrusion of a "pipe" that was positioned in 10 to 20 blow molds operating inline. The goal was to provide sufficient heat to the pipe so that inline bottles could be blown within certain time periods. With controlled parison temperature, the present era of single and multiple blow molding began.

Multiwalled blow-molded containers were produced during the late 1930s using double walled tubes, stacked sheets, or combinations of tubes and sheets. Component adhesively assembled parts were produced; now the technique has been extended with the use of more thermoplastic solvent systems and sonic bonding. Rubber-forming bags were used to produce blow-molded double- and single-walled containers. This rubber bag technique began during the 1920s with the production of single-wall blown parts. By the late 1930s, plants were producing different-shaped pipes (different-shaped water traps such as the "S") by blowing PVC against a mold using a rubber-coated spring; the spring would be positioned to provide the shape prior to blowing.

During the early 1940s, polystyrene-extruded blow-molded parts were very

popular. Major commercial, large-production parts were started during the 1950s using low-density polyethylene to make squeeze bottles. By the early 1960s, work began in using high-density polyethylene to produce extruded blow-molded milk bottles. By the late 1970s, HDPE milk bottles reached a yearly U.S. production of over three billion bottles.

Since the 1940s, developments have occurred in producing injection-blow-molded bottles and other containers. The development of marketable, large-production containers did not occur until the 1970s with stretch blow molding of 2-L carbonated beverage bottles. Most of the original work started by Monsanto used acrylonitrile (AN); however, production by others occurred with polyethylene terephthalate (PET). By 1980 over two billion PET carbonated bottles were produced annually by companies such as Amoco Chemical, Continental Group, Hoover Universal, Imco, National Can, Owens-Illinois, and Sewell Plastics.

Coca-Cola Bottle

Acrylonitrile-styrene (AN) plastic was used to produce the first commercial stretched Coca-Cola carbonated beverage bottles (two liters; 1958). The glass pinch bottle, which debuted in 1915, was being resurrected out of plastics by Monsanto Co. using Barex plastic from Sohia of BP Chemical International and DuPont's stretched injection blow molding process. Unfortunately after the production started in about eight plants with recycling facilities on the East Coast, AN was banned by the FDA because of the potential for food contamination (even though its permeability requirements really could not be determined by instrumentation available at that time).

After decades of wasted money and time by the government (i.e., by taxpayers) and the cost and time used by the plastics industry, restrictions on AN were finally lifted. However, in the mean time, PET plastics were developed, producing an avalanche of bottles that appeared commercially worldwide, beginning during the 1970s. Originally, rumors had it that "competitors" fed the FDA the "wrong" information.

Coor's Beer Bottle

During the mid 1950s Coor's beer Company in Colorado almost began using commercially stretched injection blow molded bottles. They had planned on using the injection blow molding with rotation process (Chap. 15), but unfortunately they were using acrylonitrile-styrene plastic, which, as just reviewed, had been banned by the FDA.

Recycling History

The first LDPE bottle blow molded using scrap recycled polyethylene plastic was made by Plax Corp., Hartford, CT in 1942.

Squeeze Tube

Squeeze tubes, traditionally an impact-extruded lead–tin–aluminum product, were first used as oil paint containers. September 18, 1841 is the date of the first patent. They are now usually identified as airtight, collapsible, light-proof, unbreakable, convenient and easy to use, sterilizable, and economical tube products.

Zipper

In 1851 Elias Howe, Jr. patented a device composed of a series of clasps and ribs that would join two pieces of material. Even though the concept had merit, he abandoned it to concentrate on the sewing machine. Howe's invention remained forgotten until the turn of the twentieth century when it evolved into what is known now as the zipper. Its first uses included closing money belts and tobacco pouches; it was not widely accepted by the apparel industry until the 1940s (thanks to the efforts of a Swiss immigrant in New York City). Zippers are now made of brass, aluminum, and predominantly plastics,

with the most popular types being polyesters and acetals (Chap. 15, Velcro Strips).

Waste Containers

During the early 1990s one of the largest IMM built was capable of molding parts measuring up to 6 ft × 5 ft × 4 ft. It was located in Oak Brook, IL and was owned by Waste Management, Inc., which described itself as the world's largest provider of waste- and environment-related services. At that time their annual sales were over $50 million. Its Battenfeld 4,500 T IMM and its mold [weighing 127 mT (140 tons)] produced large waste containers using recycled/virgin HDPE that replaced their metal counterparts.

The $1\frac{1}{2}$ m^3 (2 yd^3) plastic containers weigh 48 to 55 kg (105 to 120 lb) depending on design. The IMM uses two interconnecting plasticators to provide an injection rate of 18 lb/sec. Plastic containers provided major benefits. They were lighter in weight, had no need to be painted or repaired, were not subject to environmental wear and/or tearing, and had a life span at least double that of metals, which was only two to three years.

Shotgun Shells

When the first plastic shotgun shells appeared on the market in the late 1950s, sporting goods stores could not stock their shelves fast enough. Replacing paper with injection-molded polyethylene in the shell's body spelled an end to the century-old problems of moisture absorption and misfires caused by spoiled powder. The use of plastics also reduced shell jamming and enhanced the smooth operation of automatics, which were then being introduced. By the end of he 1960s, DuPont's supertough plastic technology had emerged. This material, by the late 1980s, was embodied in molded designs for center-fired cartridges of .38 caliber pistols, using casings made of DuPont's Zytel ST 901L supertough amorphous nylon. This casing was both strong enough and tough enough to withstand the explosive forces that are generated when a bullet is fired. It offered advantages ranging from consistently high targeting accuracy to decreased firing chamber wear, low-friction extraction, elimination of corrosion, and lower production costs.

Water Treatment

For almost a century many injection molded plastic components have been used in water treatment systems throughout the world. An example is DuPont's Permasep permeators for reverse osmosis (RO) water desalination, introduced in 1969. Since that time such systems have been used in thousands of installations for desalination of brackish water and seawater, and to treat waste effluents.

Profits

One might say that considering the risk involved in the business of plastics or other industries (Figs. 17-13 to 17-15) there should always be a planned profitable adventure (Chap. 5, Risks and the Products). Formalization of a profit plan leads to the attainment of profit goals. The plan should serve two functions: to evaluate alternative investments with the aim of determining the most profitable and to check the economic success of investments that have been implemented. The earlier a profitability study is carried out in the planning process, the sooner the prospects for success of a planning alternative. Unnecessary planning work, because its prospects of success are low, can thus be avoided, and decisions on investments can be taken earlier. However, the old axiom that to be successful requires that a company embrace change has to be extended to include the company's ability to anticipate when change is necessary. The growth rate for plastics versus other materials summarized in Fig. 17-23 can be related to the profitable business of the plastics industry (186, 368).

Profits and Time

Timeliness acquires significance when it is equated to monetary value. It should

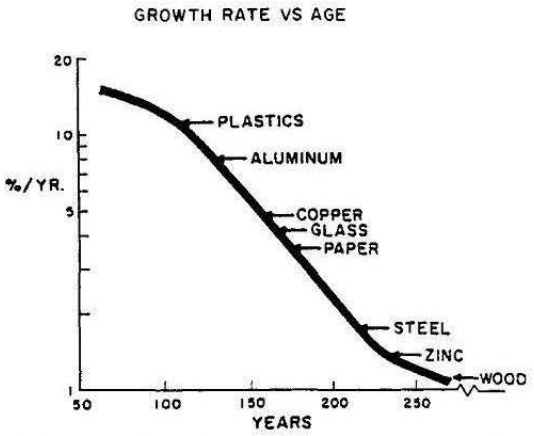


Fig. 17-23 Growth rate versus age for various materials.

sensitize everyone in the organization to the effect that his or her actions have on profitability. Because lost time cannot be recaptured, delay represents a permanently lost profit opportunity. It is important to use the time-is-profit concept. Success with profit requires keeping up to date on the endless new developments in the world of plastics to ensure the best product design meeting fabricating part performance at the lowest cost.

Plastics, Cradle-to-Grave

In cradle-to-grave analysis, plastics far outperform other materials. Studies have compared various materials on bases such as energy consumption, air emissions, waterborne wastes, and solid waste products. Life-cycle assessment is a comprehensive means of comparing the impact those different materials, product designs, fabrication processes, and waste disposal methods have on the environment. Overall this technique sets plastics in a favorable light versus competitive materials.

Future for Injection Molded Plastics

Major increases in future production continues to be achieved since injection molding plants regard themselves as a system in their own right operating to maximum efficiency as present markets expand and new ones develop. An integral feature is the complete chain of operations ranging from the organization and flow of materials, to guaranteeing quality documentation for the customer, to punctual delivery without causing excessive intermediate and final storage problems for the manufacturer.

As discussed in this book and elsewhere, the enterprise that plastics and the plastics industry have formed is nothing short of phenomenal and more advances are on the horizon. An entirely new industry emerged cresting employment for an estimated five million people worldwide with injection molding being a major contributor. Despite its youth, the plastic products industry has made a major contribution to the progress of materials and civilization as a whole. Alliances have been created worldwide as the need to exchange information grows (1, 82, 187).

Plastics, only a little over a century old (1870s), are the first new commercial material to become available in more than 3,000 years. Few, if any, other materials worldwide have had such an impact on virtually all spheres of life. What makes them even more important is that new developments will continue to evolve (materialwise, processwise, and productwise). Plastics, which have successfully conquered broad sections of virtually all spheres of life on, around, and under the earth, have demonstrated dynamic development from their infancy to futuristic highly specialized, high-performance materials and so-called high-tech applications. Their future looks very bright; growth is far from over owing to its unique blend of intuition, creativity, engineering, and science.

To ensure the worldwide dynamic growth of plastic, important areas of development continue in the areas of process science and technology, fabricating, and operations. The process science and technology area takes into consideration factors such as fabricating processes, materials, process controls, production tools, energy reductions, and waste reduction. The fabricating and operations area covers factors such as the focus on customers, production capabilities, building new plants, supplier relations, and global interrelated operations. There are many (literally thousands) of products that incorporate or have been completely converted to plastics. As reviewed, the maximum achievable

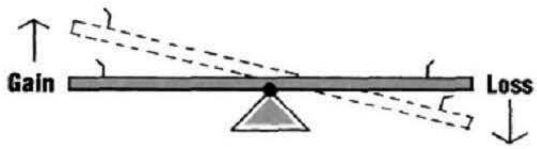


Fig. 17-24 A judicious balance of gains with potential losses.

strength of plastics has not yet been attained. This is but one example of many others that exemplifies the endless possibility for creating new and better performing plastic materials. But perfection is elusive (Chap. 5, Perfection) and gains and losses often have a way of balancing each other (Fig. 17-24).

Injection Molding in the Forefront

The profound impact of processing plastics (particularly injection molding) to people and industries worldwide is due to the intelligent applications of modern engineering and chemistry principles. For over a century, these processes and materials have exploited the versatility and vast array of inherent plastic properties as well as advancement in high-speed processing techniques. The result has been the endless development of cost-effective products.

Injection molding has the processing advantage that molded products can be manufactured economically in unlimited quantities with little or usually no finishing operations. It is primarily a mass production method, and because of high capital investment in machines, molds, and auxiliary equipment, it can operate most economically. The surfaces of injection moldings are as smooth and bright or as grained and engraved as the surfaces of the mold cavity in which they were prepared. Different types of specialty equipment are available for injection-compression molding, injection blow molding, insertion of decorative film, and coinjection (Chap. 15).

Summary

Few other materials have had such a lasting impact on virtually all spheres of life as have plastics. What is more interesting and important in this world of plastics is the endless development in all facets going from plastic materials to equipment to products to markets with injection molding being in the forefront. Plastics have demonstrated dynamic development from their infancy to futuristic, highly specialized, high-tech applications. No industry is more future oriented than the plastics industry with injection molding being a major contributor, if not *the* major contributor, to its continued success. In the future, as usual, injection molders worldwide will be operating at faster rates to tighter tolerances in order to meet the endless new customer requirements.

There are myriad injection moldable plastics with many different properties and performance characteristics to meet the many and varying commercial and industrial product requirements. Injection-molded products can range from simple to complex shapes. There are those fabricated to have exceptional beauty or aesthetic appeal, have long life, resist corrosion, provide electrical and heat resistance or insulation, meet structural loads including creep and fatigue endurances, withstand natural and human environmental conditions, and so on as reviewed in this book. Injection molding permits certain products to be produced economically, including those whose manufacture would be difficult or impossible by other processes.

Compared to other processes, injection molding has enjoyed an impressive growth rate worldwide since its inception just over a century ago but particularly since about 1940. The product design community was quick to recognize the design freedom and great versatility that these products afforded. Recognizing a growing marketing opportunity worldwide, machine suppliers initiated an endless cycle of developing new and improved injection molding machines (Fig. 17-25) to meet practically all new product design needs (Chap. 2). Figure 17-25 from Wilmington Machinery shows a year-2000 example of the continuing versatility of IMMs. It is a ten-station, rotary indexing, low-pressure structural foam injection molding machine with programmable shot sizes (Chap. 15).

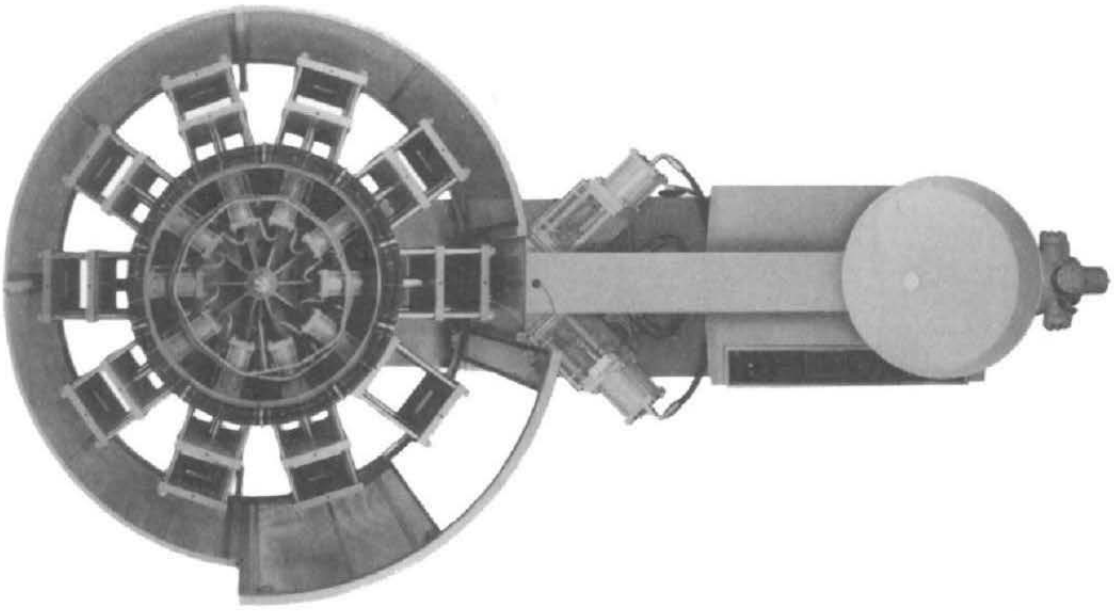


Fig. 17-25 Low-pressure structural foam ten-station indexing IMM from Wilmington Machinery.

In a marketing economy (which is to say the real world ruled by competition), injection molded products will be employed only in applications where they can be expected to bring an overall economic advantage compared with other processes and materials. In this connection it is well to note that for certain products a major competitor can be plastics processed by other methods (Chap. 16) (1, 3, 7, 10, 18, 21, 22, 31). On the basis of an overall benefit assessment one can take into account the full service of these injection molded products. It has been shown in literally millions of examples worldwide that their use not only makes economic sense but also makes contributions that range from safety and energy conservation to extension of the useful life expectancies of products.