

Field-Applied Computerized Tracking System: A Practical Approach to On-Site Quality Control

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Summary

Automation and monitoring of modern hydraulic fracturing treatments demand a unique approach incorporating intelligent data acquisition and control equipment. This paper describes how a computerized system was applied to the task.

During a treatment, several operations are conducted concurrently. Concentrated gelling agents must be precisely proportioned with various additives to form a base gel. This base gel is then blended with sand, crosslinking agents, and breakers to form the slurry that is pumped into the formation. These operations dictate the metering, measuring, and controlling of many parameters simultaneously over several pieces of mobile equipment.

Multiple microprocessor-based control modules are used to perform this task. Each module interfaces with various transducers involved in a particular operation. The use and design of these control modules are outlined, as well as the transmission of information between the modules and the operations control computer. The hardware, software, and ergonomic aspects of the system are discussed. Finally, an additional engineering computer system is outlined, including its link to the central monitor. The presentation of information in a manner to facilitate quality control is discussed. Throughout this paper, emphasis is placed on the use of computer technology to simplify and improve data analysis and quality control.

Introduction

During the late 1970's and early 1980's, the technology associated with fracture stimulation treatments went through a technological renaissance. With the development of massive hydraulic fracturing (MHF) treatments, the size and complexity of the jobs increased substantially. Fracturing treatments evolved from 60,000 gal of fracturing fluid used to transport 120,000 lbm of proppant to jobs that used more than 1,000,000 gal of fluid and 4,000,000 lbm of proppant. Both the size and the complexity of the treatment changed.

Earlier treatments usually used one fluid composition for the entire procedure. MHF treatments require the ability to tailor fluid properties and characteristics for each stage of the application. The size and volume of MHF treatments also increased the need for better and more accurate controls. A 10% metering error on a 120,000-lbm treatment could mean either having an excess of 2,000 to 3,000 gal of fluid or leaving 6,000 or 7,000 lbm of proppant on the surface. Neither condition presented major logistical problems. The same magnitude error on a MHF treatment could result in 100,000 gal of unused fluid or 400,000 lbm of leftover proppant, either of which could be significant to the well's performance.

The fluid systems used in the original MHF treatments usually consisted of a highly viscous fluid prepared from water. Enough tanks would be placed on the wellsite to contain the necessary volume for the treatment. These tanks would be filled with suitable water. A soluble polymer, potassium chloride, fluid-loss-control additives, emulsion preventers, gel stabilizers, bactericides, and buffering agents would be added to the water. Often 2 to 3 hours were needed to prepare one tank of fluid. If the total volume of the treatment required 40 to 60 tanks, days of preparation would be required before the treatment could begin. In addition to the batch-mixed materials, other additives (crosslinkers, hydrocarbon

fluid-loss materials, and proppant) were added as the fluid was being pumped.

During the last few years, the introduction of liquid fracture concentrates (LFC), a slurry of water-soluble polymer in hydrocarbon, has facilitated continuous-mix fracturing systems. This technique starts with tanks of water on location. All additives and chemicals are added to this water "on the fly" during the fracturing treatment. Specialized equipment has been developed to make this practical and possible. Because the materials must be metered in the correct proportions, at the right time, and under changing conditions, the importance of monitoring and controlling these materials has reached a new level.^{1,2}

One of the most significant characteristics of a fracturing fluid is its viscosity, which contributes to the fracture geometry, the efficiency of the fluid to create the fracture, and the fluid's ability to transport proppant into the fracture.^{3,4} The viscosity of water is modified by the addition of a water-soluble polymer. This is done by first preparing a liquid slurry of the dry polymer mixed with a hydrocarbon carrier (LFC). During the treatment, this slurry is added to the base water in an exact ratio, usually in the range of 10 gal slurry/1,000 gal of water. After the polymer has had sufficient time to hydrate, an initial viscosity of about 40 cp will be obtained. The viscosity of the fluid is then significantly enhanced through the addition of a crosslinking additive, which is usually added at concentrations of 2 gal/1,000 gal of polymer-based fluid. The addition of crosslinker creates a fluid that will achieve viscosities of several hundred centipoise. An error in crosslinker rate of 25%, or ½ gal/1,000, could cause the fluid not to achieve the desired viscosity or to overcrosslink and become ineffective. **Fig. 1** shows the effect on viscosity of modifying the crosslinker ratio for a typical fracturing fluid.

The final fluid properties are influenced by many other chemicals besides the LFC slurry and the crosslinker. These include concentrated potassium chloride solution or clay inhibitor, gel stabilizer, concentrated fluid-loss additive, emulsion inhibitor, pH buffers, and breaker solution. Each material must be added to a variable base fluid stream in precise ratios.

During MHF treatments, it is common and often necessary to have backup equipment for the critical functions. The necessity of including this equipment adds to the problems and complexities of ensuring the quality of the fluid pumped. On any given treatment, it is important to monitor, control, and record 12 or more chemical streams located on two or three different components. **Table 1** shows the various additives and rates typically needed. In addition to the chemical rates and ratios, such fluid properties as gel viscosity, fluid pH, and temperature are also monitored for quality assurance. This is true not only for the primary equipment, but also for the backup equipment if it is used.

Before the introduction of microprocessor-based monitoring systems, the majority of the information available to the service supervisor on location consisted of verbal information passed on from equipment operators. The service supervisor would analyze this information, modify it for changing conditions, and verbally inform the equipment operators of the new desired settings. The operators would then adjust their equipment accordingly. With an ever-changing set of conditions, the information soon became overwhelming and confusing.

Microprocessor-based monitoring, control, and recording equipment provides an efficient, high-speed method of processing, ad-

TABLE 1—ADDITIVE RATE SCHEDULE FOR MHF TREATMENT

Fluid Composition		Injection Rate				
2% KCl brine		30 bbl/min				
10 gal/1,000 gal LFC		20/40-mesh sand				
6 gal/1,000 gal crosslinker						
2 gal/1,000 gal nonemulsifier						
1 gal/1,000 gal breaker solution						
Stage	Slurry Rate (bbl/min)	Liquid Rate (bbl/min)	LFC Rate (gal/min)	Crosslinker Rate (gal/min)	Nonemulsifier Rate (gal/min)	Breaker Rate (gal/min)
Pad	30	30.0	12.6	7.56	2.52	1.26
1 lbm/gal	30	28.6	12.0	7.21	2.40	1.20
2 lbm/gal	30	27.3	11.5	6.88	2.29	1.15
4 lbm/gal	30	24.5	10.3	6.17	2.06	1.03
5 lbm/gal	30	21.8	9.2	5.49	1.83	0.92
8 lbm/gal	30	19.1	8.0	4.81	1.60	0.80
10 lbm/gal	30	16.4	6.9	4.13	1.38	0.69
12 lbm/gal	30	13.6	5.7	3.43	1.14	0.57
Flush	30	30.0	12.6	0	0	1.26

justing, transmitting, displaying, and recording all the data necessary to ensure a quality treatment.

To provide the required quality of fluids necessary for successful MHF treatments, monitoring, control, and metering equipment that will function in a harsh environment is needed. The system must be simple to operate and provide for manual backup in case of component failure during a treatment. After an extensive study of existing off-the-shelf hardware, the decision was made to develop a hardware system especially for this application.

A system of dedicated microprocessor-based controllers has been developed using the 16/32-bit 68000 series of microprocessors. This dedicates the processing power of a PC to each point to be controlled. Each controller is designed so that the operator may assume manual control at any time by the flip of a switch (Fig. 2). The manual control system is independent of the microprocessor, providing an extra measure of safety and allowing a job to be completed even in the unlikely event of a microprocessor failure.

A review of MHF treatments indicated that several distinct systems would be needed, each located on a specialized piece of mobile equipment (Fig. 3). The systems required and their primary functions are as follows.

1. LFC/LAS (liquid additive system) unit. Adds LFC slurry, KCl, and other additives to water to form the base gel, plus provides the necessary base gel QC functions.
2. Computer-controlled blender. Adds proppant, surfactant, fluid-loss additives, gel stabilizers, and crosslinker to the base gel.
3. Stimulation treatment vehicle. Provides a central monitoring and control center for the treatment.

LFC/LAS Unit

To perform a continuous-mix treatment, the first function necessary is the base-fluid preparation, accomplished by the LFC/LAS unit. This two-truck unit transports, monitors, and meters the LFC slurry, KCl concentrate, and other fluid-preparation additives. A centrifugal pump is used to move water from the storage tanks to the unit. The control system uses 12 identical controller modules. The base-fluid controller monitors the level of fluid in the LFC unit and adjusts the base-water rate to maintain a preset level. The remaining controllers are dedicated to each additive stream. Each monitors the water flow rate and uses preset ratios to determine the necessary control signal to be sent to the additive pumps. The equipment operator enters the set point for the controller as a ratio—i.e., gal/1,000 gal of base fluid. The proportions of the chemicals will then be controlled over a wide range of flow rates.

Each controller must determine the flow rate of its additive. The flowmeters used include turbine-type devices and optical encoders that count strokes of positive displacement pumps. The controller uses this information as feedback to adjust the designated flow rate. This control is accomplished by adjusting electrical current to an electronic over hydraulic servo valve. The servo valve, in turn, controls the speed of a hydraulic motor that drives the additive pump

(Fig. 2). Hydraulic systems were used because of their suitability to the oilfield environment and their extended operating range.

During pumping, the mixing rate may change depending on well conditions. Thus, it is more important to maintain a ratio for all chemicals rather than just a given flow rate. The controller modules accomplish this by monitoring a particular "base" rate. The base rate may be the water flow rate between the fracturing tanks and the gel mixer, the flow rate between the gel mixer and the blender, or the flow rate at the discharge of the blender (downhole rate). The point selected depends on which chemical is being added. The correct ratio is maintained by automatic responses to changes in the base rate.

The controllers also have the ability to monitor a level sensor, which may measure pressure (hydrostatic head) or capacitance or be of the float type. The controller modules linearize the indicated output level by internally storing a lookup table and interpolating between points to arrive at a corrected level for a given fluid height. This is necessary to correct the volumetric reading for tanks in which the volume is not a linear function of height—i.e., a horizontal cylindrical tank. A calibration mode is used to generate a linearization

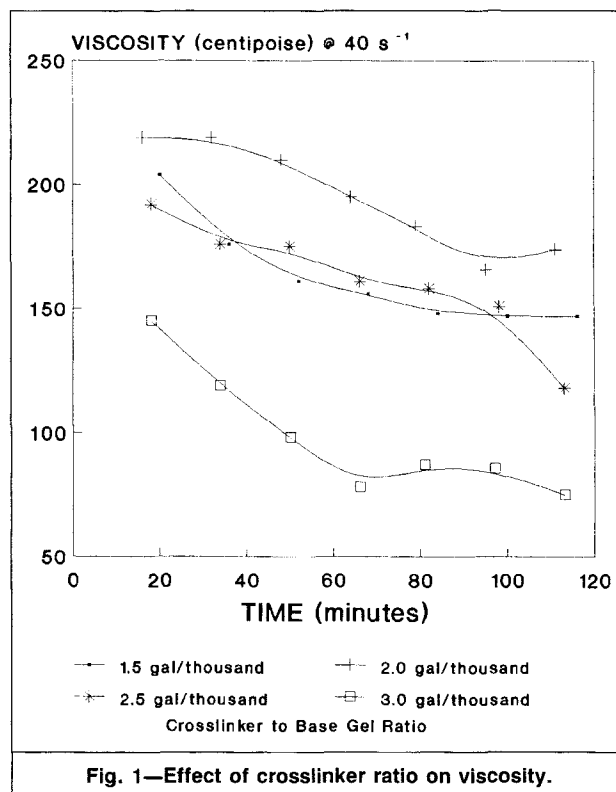


Fig. 1—Effect of crosslinker ratio on viscosity.

table automatically based on totaled volume determined by the flow input to a given controller. The level indications provide a further measure of quality control by providing a cross check on the volume pumped as determined by the flow measuring device. If fluid is not provided to a positive displacement pump, the level device also provides an indication of flow. If a valve were inadvertently closed, a positive displacement pump would still indicate flow. This situation will be determined quickly by changes in the level sensor.

In addition to the controller modules, other data must be taken to ensure the quality of the fluid being mixed by the gel blender. A module similar to the controller modules uses temperature and pH probes to sample the fluid as it is discharged from the gel blender. The controller is also interfaced to a viscometer, which samples the fluid as it leaves the LFC/LAS unit. This provides another quality check of the fluid. The viscosity is measured at a shear rate of 511 seconds⁻¹, which allows the reading to be compared directly with data taken with common laboratory instruments.

Computer-Controlled Blender

The computer-controlled blender accepts the gel blend from the LFC/LAS unit and adds the proppant and chemicals required to produce the final fracturing fluid. Fig. 4 shows how controllers were able to maintain the proper ratio of crosslinker and breaker as the base gel rate fluctuated because of changes in proppant concentration and pump rate. A special module controls the operation of the blender and the addition of proppant. The blender controller monitors the level of the fluid in the blender tube. It hydraulically controls the speed of the blender suction pump to control the base gel rate and maintains a constant fluid level in the tub. The fluid is discharged from the blender at the rate determined by job design and well characteristics. The suction rate is monitored by the blender computer, which controls the rate of proppant delivery by controlling the speed of the augers that deliver proppant to the blender tub. The auger speed is monitored by optical speed encoders affixed to the hydraulic motors that drive the augers.

To allow exact execution of a job requirement, the blender computer is preprogrammed with the proppant schedule, which is en-

tered as a function of discharge volume. The schedule may be entered either as a set of discreet steps to duplicate the way manual jobs have historically been executed or in the form of a ramp. A ramp schedule increases the proppant concentration smoothly as a function of total barrels pumped. This allows a more even distribution of proppant in the fracture. The blender augers are calibrated to deliver a certain rate on the basis of auger displacement. The calibration is adjusted depending on the proppant used. The auger efficiency varies as a function of proppant properties.

The blender computer further checks the quality of the proppant slurry by using a nuclear densimeter to monitor the slurry being discharged from the blender. The nuclear densimeter operates by passing gamma radiation through the slurry and measuring its attenuation. The blender computer uses this information to calculate the slurry density, either in units of specific gravity or weight of proppant per volume of slurry. This information may be used to adjust auger efficiency.

Local Area Network

The blender control console and LFC/LAS control console send all the data to which they have access to a well-treatment analyzer (WTA) located in the engineering monitoring vehicle by means of a local area network (LAN) (Fig. 5). The network transmits signals using fully differential line drivers over twisted pairs. A WTA acts as the master, transmitting over a separate cable pair so that it always has control of the system. The network operates at a conservative 38K baud rate to help ensure data integrity, which is verified by a check sum before being accepted.

The use of the LAN greatly simplifies the equipment setup on the site of a stimulation treatment. The single LAN cable replaces the 30 or more individual cables that would be required to bring that same data to the WTA by discreet lines. The LAN also has the added advantage of giving the service supervisor the same digital information as is being viewed by the equipment operators.

Stimulation Treatment Vehicle

The entire treatment is directed by a service supervisor, who works closely with the company representative to execute the designed

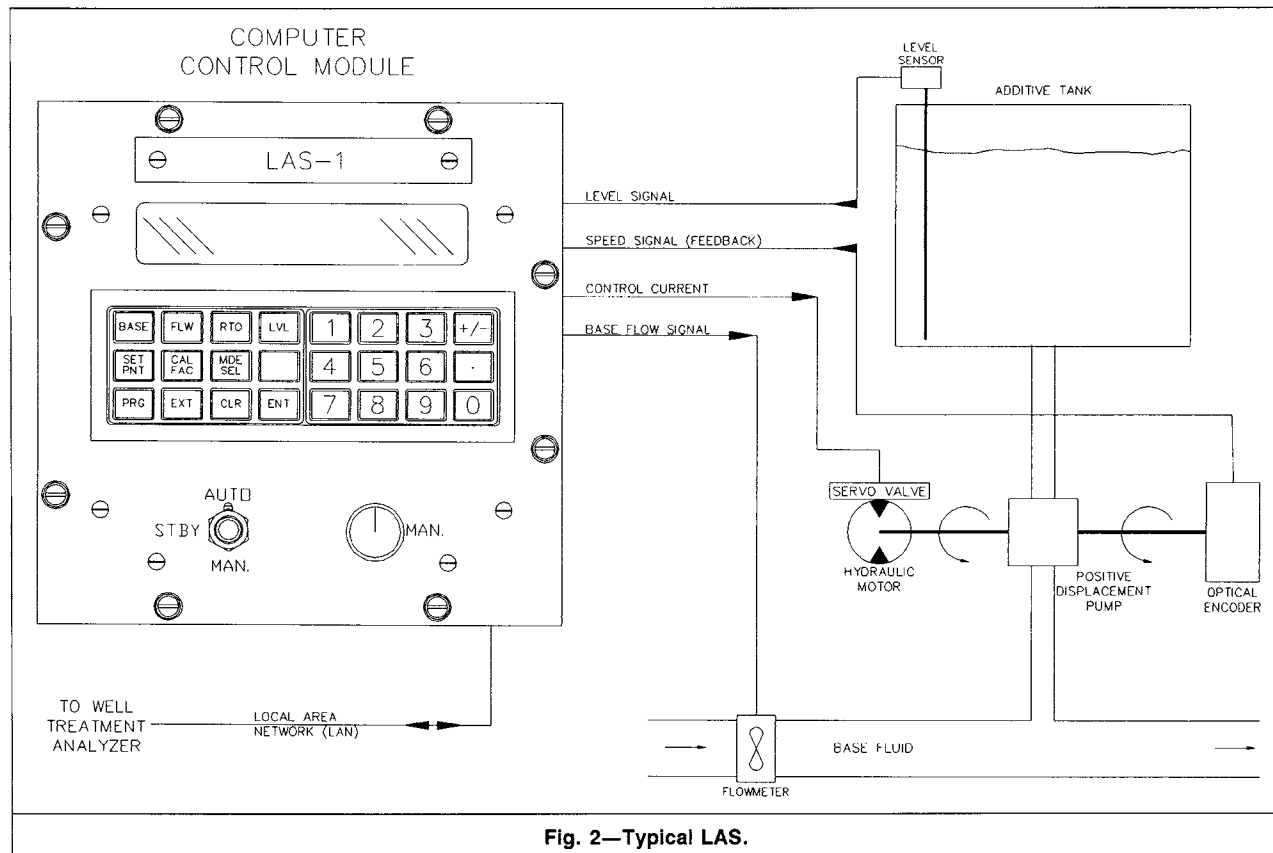


Fig. 2—Typical LAS.

treatment and to make on-site modifications as the well situation dictates. Two major computer systems are used to assist him. The WTA processes, displays, and records the necessary surface information. With this information, the service supervisor can be assured that the proper ratios of materials are being added, the treatment is proceeding on schedule, and the equipment is operating within its design performance standards.

WTA

The WTA is the heart of the stimulation system. In addition to data received by means of the LAN, signals are input directly by one of several analog or digital inputs.

On a typical job, pressure transducers are used to monitor pressure, both tubing and annulus, at the wellhead. A nuclear densimeter is used on the high-pressure treating line near the wellhead as a final verification of slurry quality. The signals to the WTA are sampled at a consistent interval of 100 msec and are then digitally processed to reduce noise. The operator may modify the nature of the

signal processing as required for a given situation. The analyzer also allows the operator to calibrate sensors and to define input parameters. The operator may also implement extended mathematical processing, such as gas equations required by foam applications.

The primary operator interface to the analyzer consists of a plasma display panel with an integral touch screen display. This technology, originally developed for military use, has worked very well in the oil field. The touch screen allows the operator to point at the action required. Context-sensitive on-line help is available to the operator at all times, which eases the burden of operating the equipment and allows the operator to concentrate on producing a good job.

The analyzer has a built-in high-resolution graphics recorder capable of graphing five parameters simultaneously. A solid-state data cassette, chosen for its inherent integrity, records job parameters. It is reliable under conditions that would corrupt more conventional media, such as magnetic tape or disks. The data on the cassette may be played back on the chart recorder and rescaled as desired for further analysis. It may also be transferred to another computer,

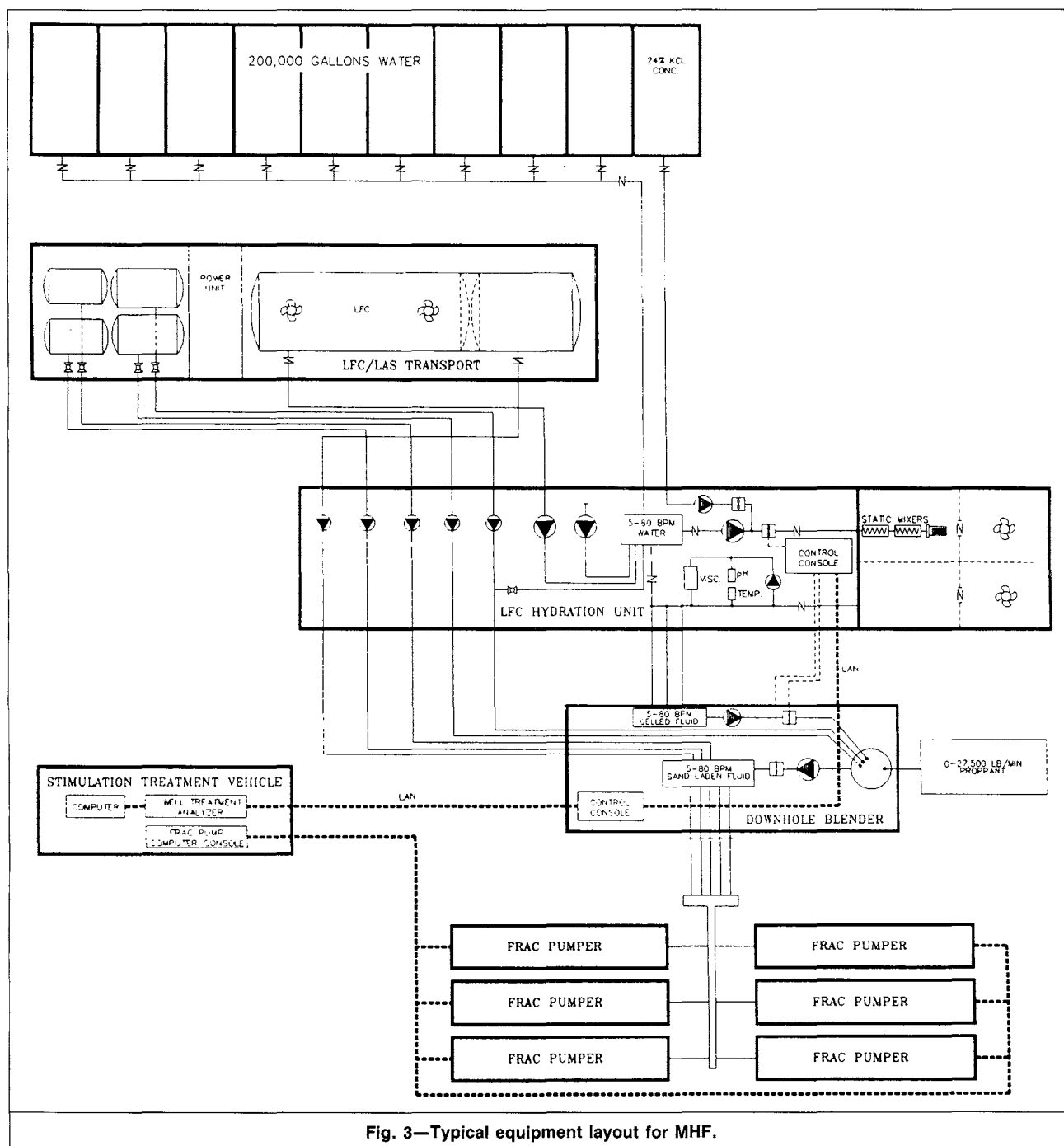
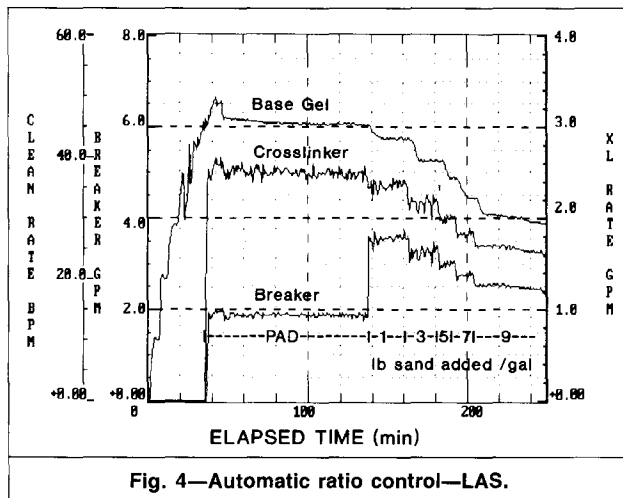


Fig. 3—Typical equipment layout for MHF.



either directly from a serial port on the analyzer or by a small hand-size data cassette reader designed expressly for that purpose.

A remote/overhead display may be connected to the unit to facilitate viewing by a larger group of people. This avoids congestion around the analyzer. A remote printer may be connected to log all job parameters.

In all cases, the service supervisor has control over what parameters are displayed and in what format. The analyzer is capable of sending the data it has collected and processed to an on-site analysis computer by means of a serial data port for further processing.

On-Site Analysis Computer

In addition to the surface information, modern hydraulic fracturing technology uses downhole data to indicate the progress of the treatment in the formation.⁵⁻⁷ This information usually is not available from direct measurements and therefore is calculated.

The actual treatment is a very dynamic process that requires the tracking of changing fluid conditions, proppant concentrations, crosslinking, and additive effects to calculate downhole conditions. An additional engineering on-site analysis computer is used.^{3,4,8}

Computer Selection Criteria

The Intel 80X86 or "IBM compatible" desktop system was selected for the following reasons.

- The available speed and processing capability were more than adequate for current needs.
- Graphics hardware and software could be integrated with the system to allow speed and flexibility for graphics presentation.
- Multiple interfaces were available and easily added to the base system to allow communications with a multitude of devices.

- Hard disk storage and retrieval with ample storage for programs and data were available.

- Because of the current popularity of this computer, a great deal of industry research and development is being made to upgrade hardware and software for these systems. System upgrades can be made easily without major modifications to maintain the current state of the art.

- The availability and cost-competitive nature of the PC market allowed the computers to be introduced rapidly to all market areas.

Configuration

The initial computer selected was a Compaq Deskpro 286™ with a math coprocessor and a horizontally mounted hard drive. A second hard drive with an independent controller was added. This is a ruggedized drive, mounted vertically.

Two display systems were made available, with text information displayed by a standard monochrome text board. Data are presented graphically on a high-resolution color monitor. For those installations that would allow more display area, a graphics board, capable of driving multiple monitors with different information, was used.

Dual serial ports, an IEEE 488 interface, and a parallel port were installed to interface with external devices.

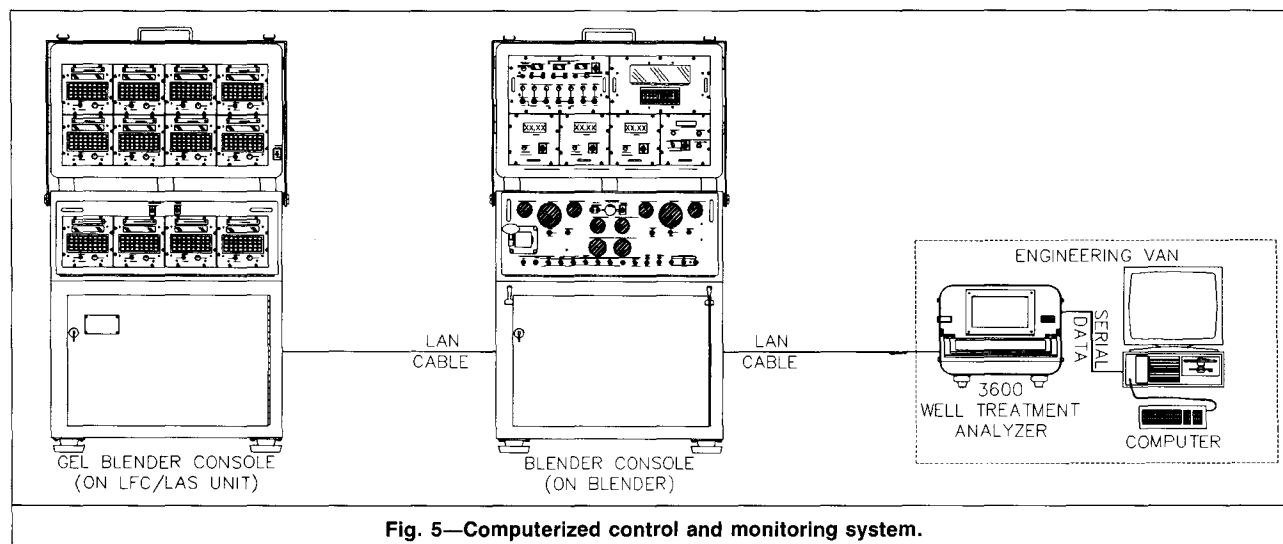
Information is stored on the ruggedized hard drive at an operator-selected interval rate.

Power

A DC power converter is used to ensure adequate and protected power. Electric generators are used to charge high-capacity 12-V deep cycle batteries. These batteries, in turn, supply power to an inverter that provides a 115-V sine wave to power the computers. In case of a generator failure, the road engine is used to provide 12-V power.

Data Acquisition

In software design, flexibility was emphasized. Because the computer would have to interface with various monitoring devices, the system would need to be capable of configuring communications by means of software. A standard RS232 interface was chosen for the primary interface. Most wireline companies and other commercially available, intelligent transducers can transmit information by RS232. There is a great deal of variance concerning the data rate, string length, handshaking, separators, terminators, and query codes required. This information is entered during setup and stored in a configuration file for future use. To avoid faulty data transmission, a test is performed on each sequence of incoming data to verify the presence of a line terminator, to verify the correct number of variable separators, and to search each numeric field for nonnumeric characters. If a fault is found, the entire string is discarded and a new request is transmitted.



It is often necessary to acquire information from more than one source. A typical application may involve communications with a WTA and a downhole pressure tool by means of a wireline company. The WTA would, in turn, be communicating with multiple control modules through the LAN.

Because the number of variables to be monitored will vary depending on the treatment, it was necessary to design a flexible data management system. During setup, the operator will identify the number of variables to be monitored and the label to be used for each. The program then allocates array space for these variables in its graphics data base. A position on the text screen is also assigned. If needed, space is reserved for displaying totals. Those variables like sand concentration and surface pressure that are used in downhole calculations are identified.

Data Presentation

To track and analyze the progress of a stimulation treatment, the information gathered must be presented in several ways.

In bottomhole pressure analysis, a logarithmic, a square root, or a Horner plot is useful. Usually, for quality control and analyzing surface conditions, elapsed time or volume is used for the horizontal axis.

The presentation of multiple graphics screens was accomplished through the use of multiple pages in graphics memory. Special function keys can then be used to select and scale the desired graphics screen.

Critical information, such as surface treating pressure and flow rate, need to be available continuously. The top four lines of each color screen are reserved for this information. A current fluid profile is also presented on each screen. Comparison of fluid position and surface treating pressure allows perforation and near-wellbore effects caused by sand loading to be identified.

A specialized, multiple-monitor graphics board was used in applications where adequate display space was available. This board has separate graphics memory and control circuitry for four monitors. The individual monitors are selected by transmitting a selection byte to I/O port 3C3 (hex). After selection, all subsequent graphics commands are routed to the appropriate graphics memory.

A standard monochrome text board is used to display numerical data. Rather than addressing this board directly, information is sent by first setting the address segment as HB000 (hex). The text screen is mapped as an offset from this location. The ASCII equivalent for the data to be displayed is then placed directly in the appropriate memory. This method of addressing the monochrome screen offers the most flexibility for different hardware configurations. During operation, a portion of the monochrome screen is reserved for comparative quality-control information (Fig. 6).

Sand concentration, based on densimeters, delivery rate to the blender, and proppant totals, is compared with the design. By monitoring this information, the service supervisor is able to verify or correct the operation of the computer-controlled blender.

Calculated and measured bottomhole treating pressure is presented for comparison when a static column or a downhole gauge is available.

Downhole Pressure Calculations

Bottomhole treating pressure is obtained by summing the effect of multiple fluid segments. A change in sand concentration, nitrogen ratio, or fluid properties triggers the creation of a new fluid segment.

Friction pressure for a given fluid segment is calculated by using a Reynolds-number-to-friction-factor correlation. Laboratory flow-loop tests are conducted to obtain friction pressure measurements for various pipe diameters. This information is combined with field data where static strings or downhole gauge data are available. A curve of shear stress vs. shear rate is made of the laminar flow rate data. The power law parameters n' and K' are calculated from this curve. A logarithmic plot of Reynolds number vs. friction factor can then be produced for the fluid in question. These data result in a smooth curve that can be fitted with a second-degree polynomial.

During a pumping operation, friction is calculated for each fluid and wellbore segment. For nitrified fluids, the density, n' and K' of the fluid are modified as a function of pressure, temperature, and foam quality.⁹ The frictional effect of proppant is accounted for by modifying an apparent viscosity term to reflect the effect of proppant. This term is then used to compute a modified Reynolds number. Friction pressure for each segment is obtained by correlating Reynolds number and the appropriate fluid curve. Bottomhole treating pressure and rate are calculated by summing the effect of each fluid segment in the wellbore from the surface to perforations.

Conclusions

The size and complex nature of modern hydraulic fracturing treatments necessitate the use of microprocessor-based equipment. Through proper design and application, computerized equipment can provide the monitoring, metering, and control functions necessary.

1. The size of treatments, coupled with the number of parameters necessary to monitor, meter, and control, makes manual operation less than optimum under rapidly changing treatment conditions and requirements.

2. The combination of microprocessor-based controller, transducer, and hydraulic servo control valves provides a simple and effective method of monitoring, metering, and controlling.

3. The use of redundant transducers and cross-check systems, along with the manual backup mode, provides an additional level of reliance and quality assurance of all critical job parameters.

4. Designed proppant schedules can be effectively achieved by hydraulically controlled auger speed ratioed to base fluid rate according to preprogrammed ratios. The proppant concentration is verified by a high-pressure nuclear densimeter.

ELAPSED TIME	SLURRY RATE	SURFACE PRESS	SAND CONC	BHTP	GAS	STAGE #
4:11:52 251.87	41.3	6504	10.2	8705	0	7
1703.5 STAGE TOTAL (bbl)	96.4		* STP 2 PSI			6523
SLURRY TOTAL (bbl)	10728.6		* KCL RATE GPM			49
CALC. CLEAN RATE (bpm)	28.2		KCL TOTAL			14856
CALC. CLEAN TOTAL (bbl)	9789.8		* BLENDER PPA			10
DESIGN SAND CONC. (#/gal)	10		* XL RATE GPM			1.57
DESIGN SAND RATE (#/min)	11844		XL TOTAL			476
DESIGN SAND TOTAL (lbs)	870321		* BREAKER GPM			2.34
CALC. SAND RATE (#/min)	12081		BREAKER TOTAL			524
CALC. SAND TOTAL (lbs)	893968		* GEL PH			7.57
HYDRAULIC HORSE POWER	6688		* GEL TEMP F			85
MAXIMUM HORSE POWER	7912		* GEL VISC CP			49
CALC. B.H.T.P. (SV) (psig)	8633		* LFC 1 GPM			0
CALC. B.H.T.P. (PS) (psig)	8858		LFC 1 TOTAL			0
STATIC B.H.T.P. (psig)	8705		* LFC 2 GPM			13
MEASURED B.H.T.P. (psig)	0		LFC 2 TOTAL			4691
B. H. SAND CONC (#/gal)	9.8		FLA BPM			0
FRICTION (psi/1000 ft)	362		FLA TOTAL			27
SAND FRICT. (psi/1000 ft)	111		BF7 RATE GPM			4.78
HYDROSTATIC (psig)	7615		BF7 TOTAL			1446
SLOPE	0.14		FRESH H2O RATE			27
FRAC GRADIENT (psi/ft)	.436		FRESH H2O TOTAL			9321

Fig. 6—Typical information displayed on text screen.

5. The use of LAN's provides a simple, effective way to transmit large quantities of data from diverse pieces of equipment to a central information center. The availability of pertinent information on the volumes, ratios, and quantities of additives provides the supervisor with the necessary input to control the treatment effectively.

6. An on-site analysis computer based on the Intel 80X86 microprocessor offers the speed, flexibility, and upgrade paths needed to calculate and present a massive amount of information in an effective format for rapid evaluation.

7. Calculated bottomhole information can be obtained by summing the effects of changing fluid segments, proppant concentrations, gas ratios, and fluid properties. This, coupled with accurately calculated friction pressures provided by the on-site analysis computer, assists the energy company engineer in determining the progress of the stimulation treatment.

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