SPE
Society of Petroleum Engineers

SPE 17315

Fracturing Process Control and Automation

by H.L. Tomlinson, A.C. Byrd, and C.F. VanBerg Jr., Halliburton Services

Copyright 1988, Society of Petroleum Engineers

This paper was prepared for presentation at the SPE Permian Basin Oil and Gas Recovery Conference held in Midland, Texas, March 10–11, 1988.

This paper was selected for presentation by an SPE Program Committee following review of information contained in an abstract submitted by the author(s). Contents of the paper, as presented, have not been reviewed by the Society of Petroleum Engineers and are subject to correction by the author(s). The material, as presented, does not necessarily reflect any position of the Society of Petroleum Engineers, its officers, or members. Papers presented at SPE meetings are subject to publication review by Editorial Committees of the Society of Petroleum Engineers. Permission to copy is restricted to an abstract of not more than 300 words. Illustrations may not be copied. The abstract should contain conspicuous acknowledgment of where and by whom the paper is presented. Write Publications Manager, SPE, P.O. Box 833836, Richardson, TX 75083-3836. Telex, 730989 SPEDAL.

ABSTRACT

As the result of studies of (1) trends in the petroleum industry (2) surveys of Halliburton field operating units and (3) surveys of operating companies, a decision was made to automate and remotely control as many well completion processes as were found to be feasible. In Phase 1 of a long range plan, fracture stimulation was automated and placed on remote control.

A dedicated team was organized to accomplish the automation. The first system is operating in the Permian Basin and has been used to fracture stimulate 30 wells as of this writing.

This paper presents the management approach to organization for the required implementation tasks. Mechanical equipment, computing equipment and software, operating procedures, and documentation are discussed. A case history of field use in the Permian Basin is presented.

INTRODUCTION

Beginning with the belief that the state of the art of pumping and blending equipment (Fig. 1) used in oil well stimulation required changes and improvements to bring it into line with the state of the art in material and data acquisition, a study was initiated. Consideration was given to the work that had been done to better explain the behavior of hydrocarbon-bearing formations during fracturing operations.[1-5] To support work such as this, pumping and blending equipment must have the capability to (1) continuously and accurately blend a number of liquid and dry additives into the fracturing base fluid, (2) measure progress of the fluid, and (3) record the entire treatment on a time base.

References and illustrations at end of paper.

A study was made in 1986 to determine market needs for fracturing equipment. Field operation (in-company) surveys, customer surveys, and equipment design surveys revealed the need for improved quality control of the on-site blending process, and for good documentation of resulting treatments. Surveys also showed that most fracturing design activity is computer assisted, therefore on-site equipment should include computer assist capability or compatibility with computers.

General design goals for the project to automate and remotely control the fracturing process were to (1) improve execution of complex job design, (2) significantly improve quality control of chemical blends, (3) reduce operational cost, (4) improve safety, (5) provide for changes in job design during progress of the operation, and (6) improve documentation of the processes.

The project was divided into two phases; Phase 1, which is now complete, developed the electronics needed and manufactured equpiment for field-testing of the control concepts. Phase 2 will provide a new design concept slurry processor, software for the central computer contained in the Job Control Center, and improved sand handling equipment.

ORGANIZATIONAL APPROACH

Once the decision was made to implement a program of automatic and remote control of the fracturing process, high priority was given to accomplishing the task without delay. Conceptual planning was first done by a small panel of management, technical, and field personnel. Design and development were (and are being) performed by a team assembled for the task. These considerations were made in establishment of the team.

HALLIBURTON EXHIBIT 1029
Halliburton Energy Services, Inc. v. U.S. Well Services, LLC, IPR2023-00557, Page 1

Downloaded from http://onepetro.org/SPEPBOGR/proceedings-pdf/88OGR/All-88OGR/SPE-17315-MS/2023608/spe-17315-ms.pdf/1 by Robert Durham on 11 August 2022

1. In general, service trucks and associated equipment are designed for rough service and are durable. Electronic equipment tends to be delicate and complex to operate.

2. Components of mechanical designs can often be purchased at local outlets. Electronics tend to be custom-designed and available from only factory sources.

3. Computer programs associated with the system are almost entirely custom-developed for the needs of the system.

4. Advice and critiques of field personnel, who would be end users of the fielded system, were needed throughout the design and development process.

A special project was initiated to accomplish the interaction of electronic control equipment and software with oilfield service equipment. All disciplines required (electrical engineers, mechanical engineers, programmers, etc.) were brought together into one facility and under supervision of a single project leader (Fig. 2).

A group of four veteran field personnel, each of whom has at least 20 years of experience in well stimulation and related work, was selected for a consulting role during development, and to help introduce new systems to the field. The group contributed such information as well treatment conditions, customer needs, and customer preferences. On a bi-monthly basis, the advisory group met with the developers to review progress and make recommendations.

One group member is the division engineer in the Permian Basin area where the first automated unit is in service.

ELEMENTS OF THE SYSTEM

A diagram of the system discussed in this section is at Fig. 3.

Mechanical

2000 HHP Pump

Contributing to the ease of automation and remote control of the system is a 2000 hydraulic horsepower triplex pumping unit (Fig. 4) capable of pumping 22 bbl/min at 3700 psi.

Concentration of this much horsepower into one unit run by a single diesel engine (1) simplifies control of pumping rate, and (2) minimizes hookup time. Pumping units have control loops to adjust engine speed, select transmission gears, and control pumping pressure.

80-bbl Blender

A special 80-bbl blender is equipped with electromechanical controls and an additive metering pump that will handle all known additive fluids.

The blender has incorporated 11 control loops to monitor and adjust liquid additives, proppant delivery, engine control, dry additives, and mixing tub level.

Enclosures

Ruggedized enclosures are provided to house and protect electronic equipment. One of the goals of the projects was to develop electronics packages for the fracturing equipment that would give it the equivalent service life of other subsystems mounted on the unit. Quick repair on location without the services of highly trained electronic technicians was required. The resultant enclosure (Fig. 5) was a cast aluminum, shock-mounted case with environment control features (heat and humidity) and a quick-opening lid assembly. This assembly provides for rapid replacement (2 min. or less) of all control electronics contained therein.

These additional items of mechanical equipment were necessary.
1. Rough service sensors and actuators.
2. Reliable, rough service communication cables and connections.

Electronic Equipment

Controller

Controller electronics were designed so that the same hardware could be used on all mechanical equipment (pump trailer, blender, instrument skid, etc.) with software developed for each specific application. This total system design approach gave design consistency among various pieces of equipment and provided design time economy.

The controller (Fig. 6) is microprocessor based, with I/O drive, memory, processor, and signal conditioning all included in one ruggedized circuit module.

Data Communication

Communication among the devices is provided by a local area network (LAN) in which each node (terminal) is wired in series with the others. Referred to as "token ring topology," this technique essentially places all devices in a connected ring, with control sensing that allows devices to communicate in turn without interfering with each other. The high speed nature of the system ensures that there is no communication delay caused by netting all devices together.

Since all data and control commands are sent over the LAN (Fig. 7), it is the most critical element of the entire system; with this in mind, redundancy was designed into the system by making it a dual token ring. This system, developed for portable military applications, is fault-tolerant, and can be characterized as self-healing. For example, if connecting cables are cut, signals will automatically be reversed at the terminal nearest the cut, and will be sent to their destination by travelling in the opposite direction around the ring. If two breaks occur, those terminals still in connection with each other will continue to communicate, maintaining the same procedures with each other as when the system was whole.

Protocol is multi-master, so that a given piece of equipment can be operated by more than one interface device. The LAN can be used with one unit (stand alone) or with up to 30 pieces of equipment.

HALLIBURTON EXHIBIT 1029
Halliburton Energy Services, Inc. v. U.S. Well Services, LLC, IPR2023-00557, Page 2

Downloaded from http://onepetro.org/SPEPBOGR/proceedings-pdf/88OGR/All-88OGR/SPE-17315-MS/2023608/spe-17315-ms.pdf/1 by Robert Durham on 11 August 2022

Computer

The central computer and displays have been selected and assembled (Figs. 8 and 9), however, software is still being developed as of this writing. An industrial version of a mini computer was selected as the central processing unit. Job data are passed from the LAN to the computer through a parallel interface. Control functions can operate independent of monitoring and on-site analysis.

Remote Control

One of the goals of this project was to provide remote control panels which were (1) easy to use, (2) light weight and waterproof, and (3) designed for safe operation. Hardware selected include membrane switch panels with a 4 in. x 9½ in. LCD (liquid crystal display) housed in a military type waterproof case (Fig. 10). Front panel labeling and graphics on the LCD clearly indicate the purpose of each button. All control functions, (for example, "engaging transmission") require pushing two buttons at the same time, therefore, it is extremely unlikely that operators will accidentally cause an action not planned. Some features of the fracturing pump trailer remote control unit are

1. Over-pressure protection
2. Automatic rate (fixed or continuously variable)
3. Automatic pressure limit
4. Up to 10 trailers controlled from one panel.

Control Loop

During a fracturing treatment, additives and proppant are added to base fluid by some predetermined ratio, so the rate and volume of the base fluid becomes the reference for automatically controlling fluid additives and proppant. Consequently, base fluid properties are critical to the blending process. For redundancy, four different methods of obtaining base fluid rate are provided (in order of priority).

1. Flowmeter
   A. Magnetic
   B. Turbine
2. Automatic Calculation
3. Operator input from job rate

In this system, control of additives is accomplished by electro-hydraulic valves which govern the speed of the additive pump drive motor. Base fluid is measured with a flowmeter, and additive rates with a speed sensor. A predetermined ratio (usually in gal/1000 gal or in lb/gal of base fluid) is entered on the interface panel. The system continuously checks (electronically) and adjusts additive rate to maintain the precise ratio between the base fluid rate and additive rate.

A typical ratio control loop is shown in Fig. 11.

FIELD TESTING

Phase 1 equipment was field tested in the Permian Basin beginning in early November, 1987. Features most intensely evaluated were
1. Equipment operator acceptance of controls
2. Quality control of blending function
3. Reliability of local area network (LAN)
4. Sensitivity of automatic controls to real well conditions.

Although testing is continuing as of this writing, some tentative conclusions may be made.
1. Operators trained on this equipment were personnel having previous experience on manually controlled units of the same type. Acceptance of the equipment was good because the new blender controls gave the operator more time to tend to other duties on the blender, such as replenishment of material inventories, observing processes, etc. Automatic rate control on the pumping unit provided smoother rate changes and more precise rate control.
2. Ratio of proppant and chemicals to base fluid is more precise, a fact attributable to the mixing tub level control system. This system is designed to maintain a constant base fluid rate instead of holding a precise tub level.
3. No failure of the local area network (LAN) has been noted since testing began.

CASE HISTORIES

Thirty fracturing treatments have been run in 1987, using Phase 1 equipment; all of these jobs were run in the Permian Basin. One typical well case history is described below.

A CO_2 foam fracturing treatment was performed on a Permian Basin well. Pertinent data:

Treating depth	6800 ft
Pump rate	24 bbl/min
Total sand	85,500 lb
Sand delivery rate	Ramped from 1 lb/gal to 4 lb/gal
Total fluid	28,600 gal
Total CO_2	155 tons

Downhole combined rate was held constant, therefore, the slurry of sand and gelled fluid was ramped (increased at an even rate without sudden changes) upward as sand increased and CO_2 was ramped downward. This was accomplished automatically by the pumping units. Slurry pump rate was set at +0.00168 bbl/sec and CO_2 pump rate was set at -0.00168 bbl/sec and activated as sand delivery started. The resulting downhole rate was constant, providing good sand concentration delivery. Fig. 12 shows curves tracing sand concentration, flow rate of total commingled fluid, and casing pressure.

CONCLUSION

Control systems and equipment developed for Phase 1 have functioned as expected. Field testing to date has demonstrated that a serial network control loop (LAN) is usable in oilfield conditions. Also additive metering with electronic controls is accurate and should provide good quality control. More qualitative data is needed from actual jobs to verify quality control of the fracturing fluid. Phase 2 development should provide equipment to evaluate control of the entire job.

HALLIBURTON EXHIBIT 1029

Halliburton Energy Services, Inc. v. U.S. Well Services, LLC, IPR2023-00557, Page 3

Downloaded from http://onepetro.org/SPEPBOGR/proceedings-pdf/88OGR/All-88OGR/SPE-17315-MS/2023608/spe-17315-ms.pdf/1 by Robert Durham on 11 August 2022

REFERENCES

1. Daneshy, A.A., Slusher, G.L., Chisholm, P.T., Magee, D.A.: "In-Situ Stress Measurements During Drilling," SPE Paper 13227 presented at the 1984 Technical Conference and Exhibition, Houston, TX, September 16-19.

2. Nolte, K.G., and Smith, M.B.: "Interpretation of Fracturing Pressures," J. Pet. Tech. (September, 1981) 1767-1775

3. Nolte, K.G.: "Fracture Design Considerations based on Pressure Analysis," SPE Paper 10911 presented at the 1982 SPE Cotton Valley Symposium of the Society of Petroleum Engineers.

4. Soliman, M.Y., Venditto, J.J., and Slusher, G.L.: "Evaluating Fractured Well Performance Using Type Curves," SPE Paper 12598, presented at the 1984 Permian Basin Oil and Gas Recovery Conference, Midland, TX, March, 8-9.

5. Conway, M.W., McGowen, J.M., Gunderson, D.W., and King, D.G.: "Prediction of Formation Response From Fracture Pressure Behavior," SPE Paper 14263 presented at the 60th. Annual Technical Conference and Exhibition SPE, Las Vegas, NV, September 22-25, 1985.

ACKNOWLEDGEMENTS

The authors thank the management of Halliburton Services for their support in this effort and for permission to prepare and present this paper. Special thanks are due the project advisory group of Tom Garvin, Pat Chisholm, Danny Dorsey, and Chuck Morey (all of Halliburton) for their many hours of design review and helpful input.

Downloaded from http://onepetro.org/SPEPBOGR/proceedings-pdf/88OGR/All-88OGR/SPE-17315-MS/2023608/spe-17315-ms.pdf/1 by Robert Durham on 11 August 2022

HALLIBURTON EXHIBIT 1029

Halliburton Energy Services, Inc. v. U.S. Well Services, LLC, IPR2023-00557, Page 4

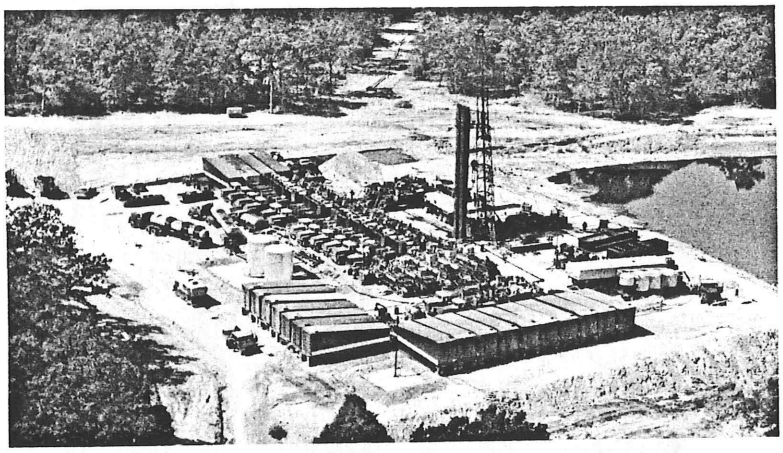

Fig. 1—Fracturing treatment equipment.

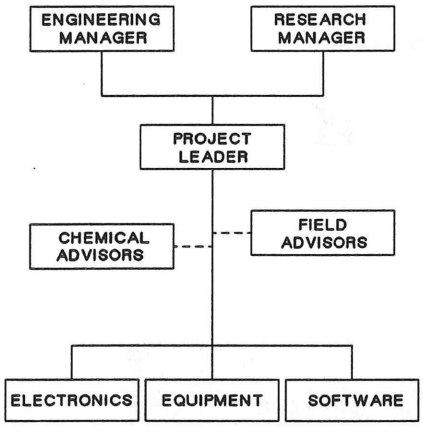

Fig. 2—Project organization chart.

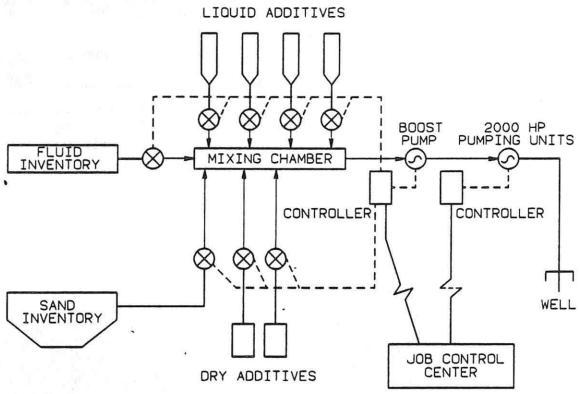

Fig. 3—Fracturing treatment process.

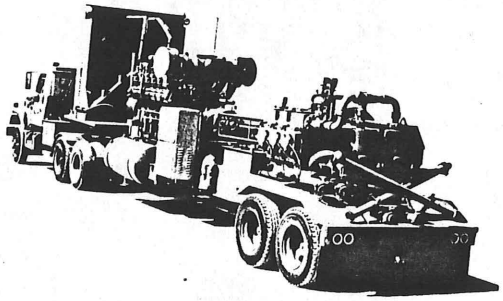

Fig. 4—2000 HHP triplex pump.

HALLIBURTON EXHIBIT 1029
Halliburton Energy Services, Inc. v. U.S. Well Services, LLC, IPR2023-00557, Page 5

Downloaded from http://onepetro.org/SPEPBOGR/proceedings-pdf/88OGR/All-88OGR/SPE-17315-MS/2023608/spe-17315-ms.pdf/1 by Robert Durham on 11 August 2022

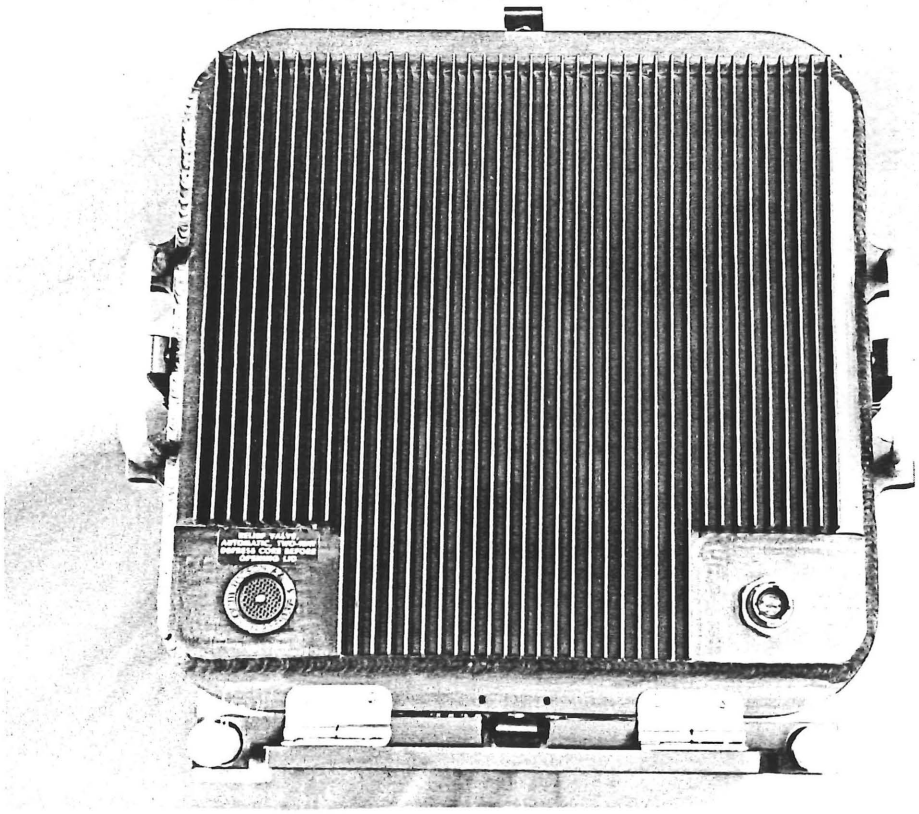

Fig. 5—Electronic control enclosure.

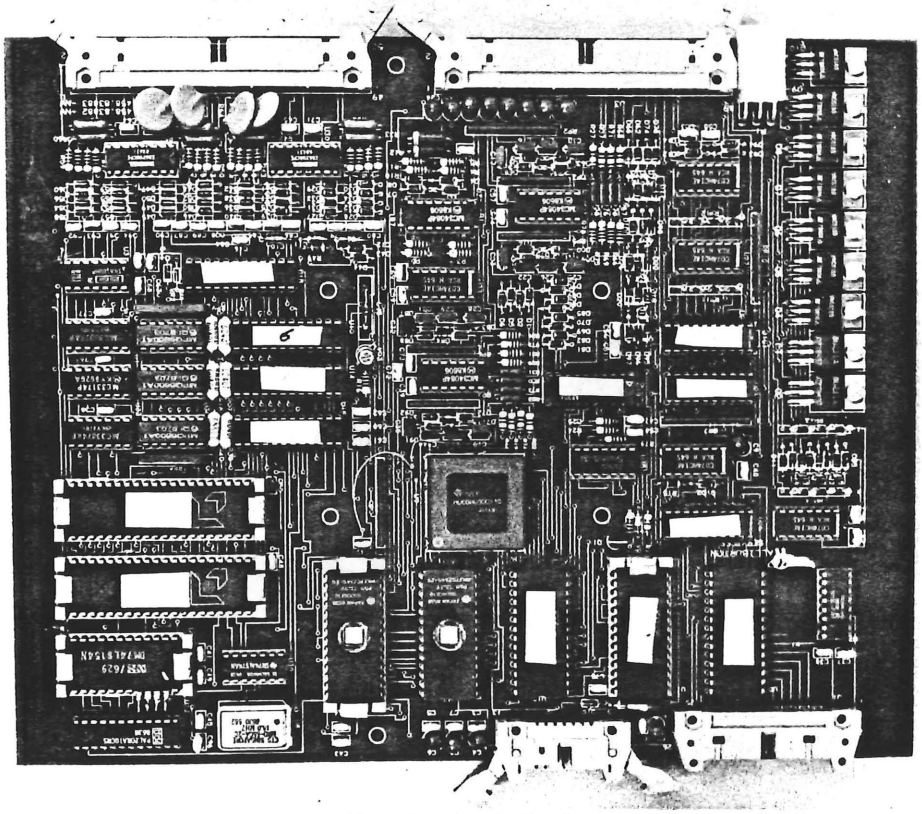

Fig. 6—Controller circuit card.

HALLIBURTON EXHIBIT 1029
Halliburton Energy Services, Inc. v. U.S. Well Services, LLC, IPR2023-00557, Page 6

Downloaded from http://onepetro.org/SPEPBOGR/proceedings-pdf/88OGR/All-88OGR/SPE-17315-MS/2023608/spe-17315-ms.pdf/1 by Robert Durham on 11 August 2022

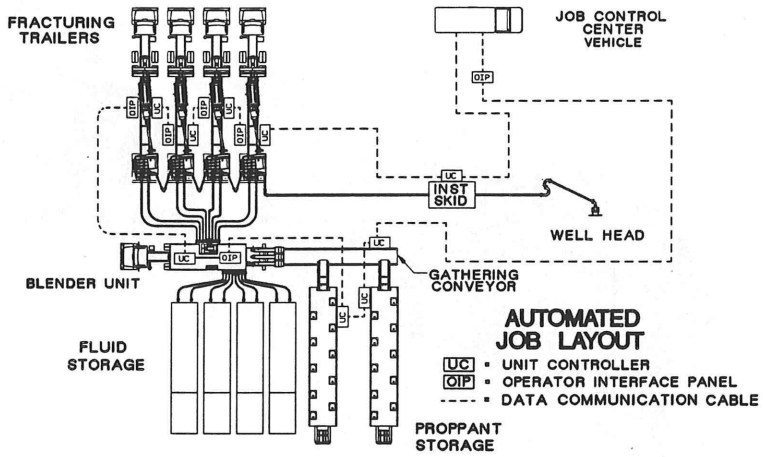

Fig. 7—Remote equipment using local area network (LAN).

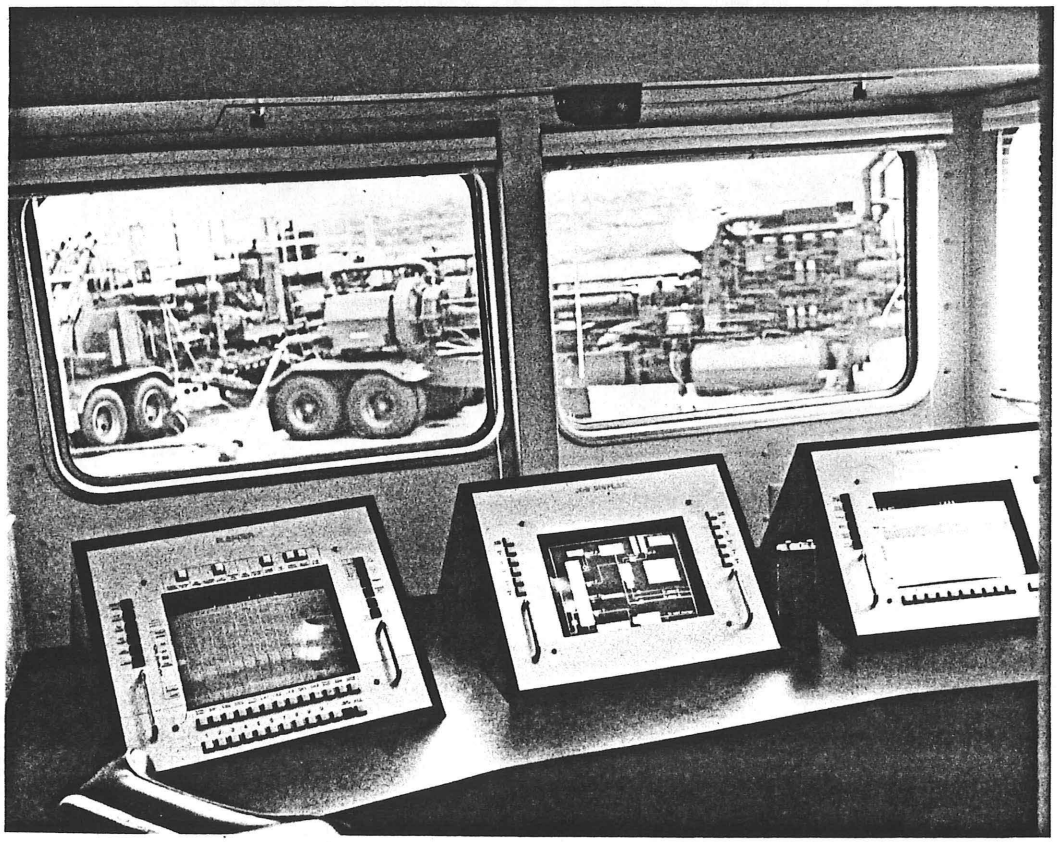

Fig. 8—Interior of job control center.

Downloaded from http://onepetro.org/SPEPBOGR/proceedings-pdf/88OGR/All-88OGR/SPE-17315-MS/2023608/spe-17315-ms.pdf/1 by Robert Durham on 11 August 2022

HALLIBURTON EXHIBIT 1029
Halliburton Energy Services, Inc. v. U.S. Well Services, LLC, IPR2023-00557, Page 7

Fig. 9—Exterior of job control center.

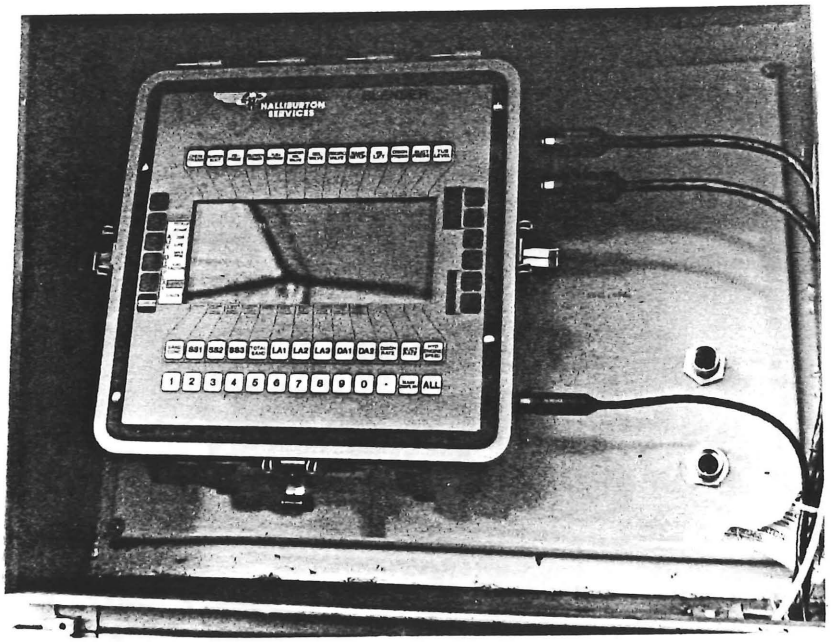

Fig. 10—Ruggedized, portable remote control unit.

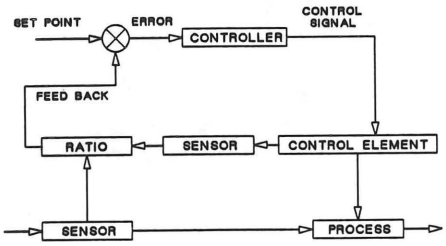

Fig. 11—Typical control loop.

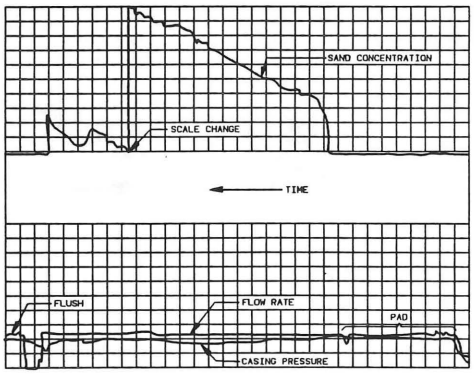

Fig. 12—Treatment chart from typical Permian Basin CO_2 foam fracturing treatment.

HALLIBURTON EXHIBIT 1029
Halliburton Energy Services, Inc. v. U.S. Well Services, LLC, IPR2023-00557, Page 8

Downloaded from http://onepetro.org/SPEPBOGR/proceedings-pdf/88OGR/All-88OGR/SPE-17315-MS/2023608/spe-17315-ms.pdf/1 by Robert Durham on 11 August 2022