AUTOMATED CEMENTING DATA ACQUISITION SYSTEM

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ABSTRACT

This paper discusses the use of a data acquisition system to provide higher quality cementing services at lower costs. Using low power microprocessors combined with reliable sensors for pressure, rate and density measurement of cement slurries the data gathered can be used to help prevent abnormal jobs, keep slurry density within program limits and provide system maintenance indicators.

INTRODUCTION

Requirements exist to document cementing jobs more accurately than the old job log in a cementer's notebook. In the current system, bourdon-tube pressure chart recorders and electric pen analog density recorders provide some information; slurry rate and total volume figures are manually recorded from a tachometer. This system does not lend itself easily to advanced computer analysis techniques which include comparing actual problem formation jobs with the previously planned cementing program.

Real time job monitoring can be used to improve cementing success. By correcting discrepancies between the planned program and the actual measurements, problem jobs can be avoided. This includes "changing pump rates to maintain freefall rate at the desired level for good mud displacement efficiency in annulus, reducing the pumping rate if partial or complete mud returns are lost, correcting density of cement slurry if it is out of range, and terminating the job because of high surface pressure or to prevent overdisplacement." Analysis of data collected by these systems is invaluable for predicting future cementing performance. By examining problem jobs, "future cases of channeling, fluid incompatibility, casing hardware problems and deficiencies in job execution usually can be prevented or corrected on future jobs".[1]

The new system (Figure 1) addresses some of these problems by storing pressure (tubing and annulus), rate (down hole and returns) and density (mixing and downhole) values every second while simultaneously generating a graphic representation of these values. The information can then be analyzed to determine whether the slurry was properly placed, proper amount of material was used and that it was mixed correctly.

Reliability and versatility were the keys to this design project. The following sections describe the design and operation of an electronic instrument which would survive in the oil field environment and still provide accurate data collection and analysis.

SYSTEM RELIABILITY

A modular data acquisition system allows information to be collected from many discrete locations at the job site and combined into one job record. The display units perform the analog to digital (A/D) conversion of transducer signals into data which can be stored by the recording unit. The unique part of the system is the Local Area Network (LAN) over which these units communicate. By using a portion of the industry standard Synchronous Data Link Control (SDLC) data transfer protocol to quickly and reliably move information between units, we can set the stage for real-time data acquisition.

Recording Unit (Figure 2)

A single board computer with associated peripherals is used to collect data, control the LAN, store data on 3.5 in. floppy diskette, display data on a graphics printer, and format data for communications with the customer's computer. A keyboard allows the operator to customize the chart display for each job and provides a means of data entry for system control. An optional video display is used for system troubleshooting and eventual display of real time data at the central collection point.

This is the heart of the system but through a series of redundant battery backed memories in the display units, is not absolutely essential to run the job. This built in reliability measure gives added support to using this type of electronics in the field, since the environmental limitations of floppy disks and printers require the recording unit to be protected from temperatures below 0°C and from direct exposure to rain and snow.

The recording unit polls each of the display units once each second, stores the data on disk and plots any three of the variables on a strip chart format. The unit controls up to 31 display units on the network. Once the job is complete, a playback mode can be entered which allows either tabular or strip chart display of any of the values recorded during the job (See example cases). In the event something happened to the recording unit during the job, it can be used after the job to download data from the display unit memory, which has battery power.

The system can currently store seven hours of job data on a floppy disk. Keyboard entries include event markers which comprise a job log to include start, stop, pause, lead cement, tail cement, spacers, displacement, plug dropped, plug landed. English or metric units allow worldwide use. Low power, 12VDC operation allows easy power connection in any environment including one installation in a hazardous zone 2 offshore area in which the system is in an air-purged enclosure.

Display Unit (Figure 3)

A microprocessor based panel display was designed using low power/ wide temperature range IC's and packaging the electronics to survive all oil field environments. The display will accept signals from a variety of transducers and will provide transducer excitation where necessary. It then converts analog signals to digital pulses which can be counted and filtered using digital filtering techniques. A battery-backed random access memory(RAM) allows the unit to store transducer characteristics between jobs along with the most recent seven hours of unit operation.

The display software can be reconfigured from the front panel keyboard to allow changes to engineering units, transducer types, transducer calibration characteristics, zero signal offset, alarm setpoints and display address on the LAN.

Values from two transducers can be displayed in one unit which allows the special case of a twin pumping unit to combine the rate from both pumps and display total rate and total volume. Combined values can then be transmitted to the recording unit.

Since most transducers have some non-linearities in their output we have compensated for this problem by incorporating a 14 point piecewise linearization routine into the calibration procedures. This allows the transducer to be characterized over it's complete operating range and provides much more accurate data. In addition to this calibration table there is also a digital filter which allows for better resolution in measuring flow signals by taking longer samples at lower rates. In the case of density measurement the Poisson distributed data from the gamma ray source is filtered by allowing values within the first standard deviation to be quickly passed through to the calculation routine. Sensitivity and accelerator factors combine to produce a quick response density calculation. By including a frequency counter as part of the display unit, problems can be quickly isolated and calibration becomes much easier.

Digital Radioactive Densometer (TDRAD)

The TDRAD operates entirely different than radioactive densometers currently in use in the field. The measuring range has been extended to cover 0 to 24 lb/gal. Response time has been decreased such that with a step change in fluid density, an accuracy of 0.1 lb/gal can be obtained in less than five seconds. The high voltage supply has been moved to the detector head along with the comparator and cable line driver. This results in greater reliability because of reduced sensitivity to noise, moisture and cable problems. The increased response provides much better slurry mixing since the operator receives "immediate" feedback and tends to settle on the program slurry weight much faster with fewer oscillations.

Pressure Transducer

The 4-20 mA pressure transducer provides accurate (± 0.5%) data from both tubing and annulus of the well. Again this sensor was chosen because of its resistance to moisture and cable problems. It can be mounted any-where in the line using a standard WECO figure 1502 high pressure connection. The display unit is only programmed with zero and span values for this transducers calibration since linearity, hysteresis and repeatability all fall within acceptable limits of the straight line approximation.

Rate Transducer

The primary means of measuring rate is to count revolutions per unit time of the input shaft of the positive displacement pump. While this is the most consistent method there have been some non-linearities discovered here. The values will depend on pump efficiency, maintenance factors and the fluid being pumped. Example transducer values which were measured on one pump in the field are shown in Figure 4.

By actually programming these numbers into the display unit a very accurate rate/total volume measurement can be obtained. Typically, a sprocket is attached to the input drive shaft and a magnetic pickup in close proximity generates pulses which are counted over a specified time interval. A digital filter technique provides accuracies of at least 1.0 %.

The alternative method of rate measurement is with a flowmeter. A special cementing flowmeter has been designed to take into account the heavy slurries. By special calibration techniques, the flowmeter can measure 14 lb/gal cement within ± 2.2% over the flow range 2 to 10 bbl/min. Some special consideration must be taken into account when using turbine flowmeters.

1. The calibration f/Q or pulses per unit volume is related to f/v or frequency/kinematic viscosity by a function phi which is a smooth curve which is "linear" in a certain range.[2] (Figure 5).

2. Non-linear performance occurs at lower f/v values, low flow rate and high viscosity. The meter should be oriented on the job in the same manner as when calibrated (vertically in our case). Empirical data collected during calibration should be entered into the display unit since each flowmeter has its own personality.

Maintenance Factors

Statistical maintenance records have been difficult to collect because of the enormous amount of paperwork involved. This system allows automatic collection of pressure/rate/density information which, when combined with actual maintenance pulled on a particular pump can lead to detailed life expectancy ratings for pump components. This data combined with a preventive maintenance program will greatly improve equipment reliability.

SYSTEM VERSATILITY

Simplified operation of all system components allows the operator to be on line almost immediately after receiving his equipment. Because the introduction of microprocessor based equipment is often met with some resistance, all attempts have been made to make the system user friendly.

The recording unit has been configured and tested and all display units were calibrated with their respective transducers. The operator simply connects transducer and LAN cables and turns on the power. The system automatically begins recording data as soon as pressure exceeds 100 psi and rate exceeds 1 bbl/min. The operator must enter job events if a complete job log is expected but this is not a requirement. While the standard job runs automatically, the system can be configured to display data from any of the displays connected to the LAN. (e.g. tubing pressure, downhole rate and density).

All data is stored as 32 bit floating point numbers so no resolution is sacrificed. This information can be transferred directly to the customer on 3.5 in. CP/M format diskette or to a different operating system (e.g., IBM-PC DOS) via the RS-232 port. This extends to actually transmitting data via MODEM to remote monitoring locations as in the third case discussed below.

CASE STUDIES

Systems have been fielded to date in both US and international locations. The US systems have been used successfully on over 100 jobs in the past year.

The first example demonstrates correlation of predicted cementing job simulation pressures with actual measured pressures. Figure 6 shows the job simulation compared with actual data recorded by the data acquisition system. Figure 7 is the same data in a strip chart format (8 5/8 inch liner job at 4400 ft.).

A second case (Figure 8) compares data plotted from the data acquisition system with simulation data on the same chart. (16 in.innerstring at 1500 ft.).

The third case (Figure 9) took place on an offshore rig and included telemetering cementing data to the customers home office. This chart shows the standard pressure, rate and density traces in their respective tracks for ease of interpretation. The job was a 11 3/4 in. intermediate string at 12,000 ft. with 13.6 lb/gal Trinity lightweight lead cement and 16.4 lb/gal class H tail. Mud weight was 12.2 lb/gal. Data was recorded and transmitted successfully except for a short power outage on the display units. After reconnecting power the job resumed as normal with only slight loss of data. This demonstrates the reliability and recoverability of the LAN.

CONCLUSION

The advent of wide temperature range/low power microprocessors combined with reliable sensors for pressure, rate and density measurement of cement slurries has allowed production of a data acquisition system which will provide a source of information for engineers working with abnormal cementing jobs. The system makes the cementer's job easier and helps keep slurry density within program limits. The net result is a higher quality job at lower cost with the added advantage of detailed data storage for predicting the outcome of future jobs. In addition, this data base can be used to generate preventive maintenance guidelines for replacing pump parts before failure occurs.

REFERENCES

1. Smith, R.C.:"Improved Cementing Success Through Real-Time Monitoring," Journal of Petroleum Technology (June 1986),619-620

2. Shafer, Montgomery R.:"Performance Characteristics of Turbine Flowmeters,"Journal of Basic Engineering (Dec 1962),471-485

3. Eckerfield, Robert J.:"A Drilling Data Acquisition System," paper 801-460 presented at the Spring Meeting of the American Petroleum Institute, Pacific Coast District, May 12-14, 1970.

4. Smith, R.C. :"Successful Primary Cementing Can Be a Reality," Journal of Petroleum Technology (Nov 1984), 1851-1858

5. Smith, R.C., Beirute, R.M. and Holman, G.B.:"Postanalyis of Abnormal Cementing Jobs using a Cementing Simulator," paper SPE 14201 presented at 60th Annual Technical Conference of the SPE, Las Vegas, NV, Sep 22-25, 1985.

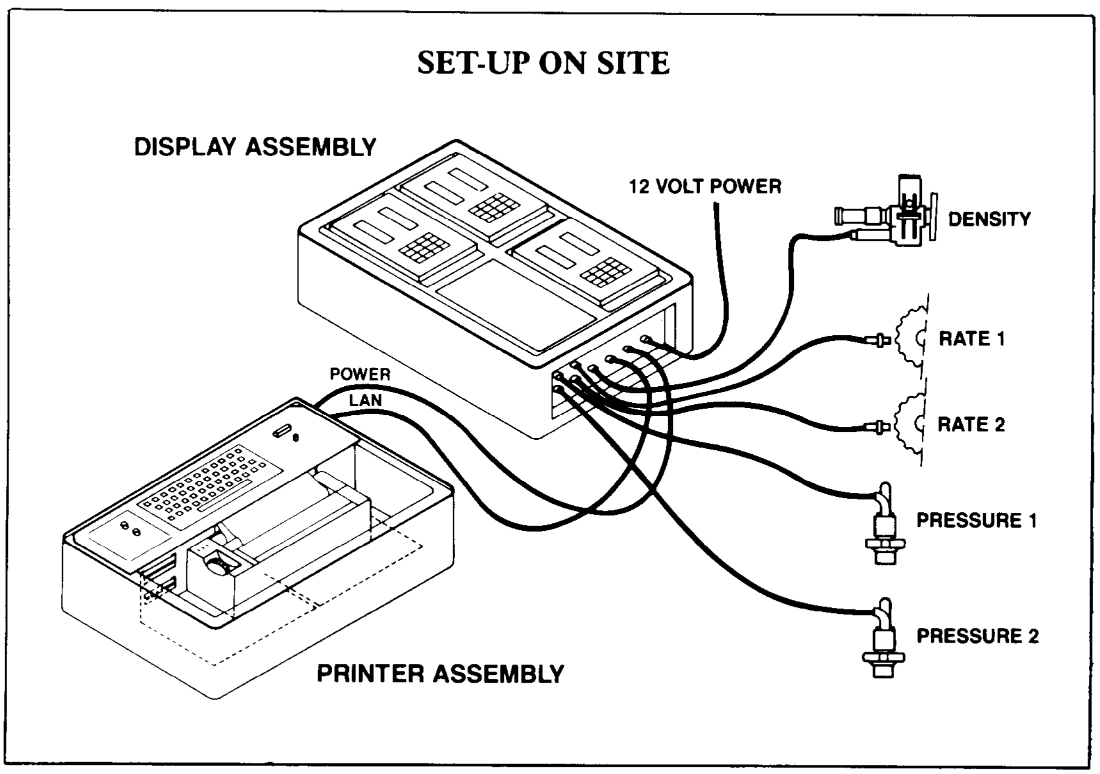


Figure 1—Automated cementing data acquisition system (LANMARC)

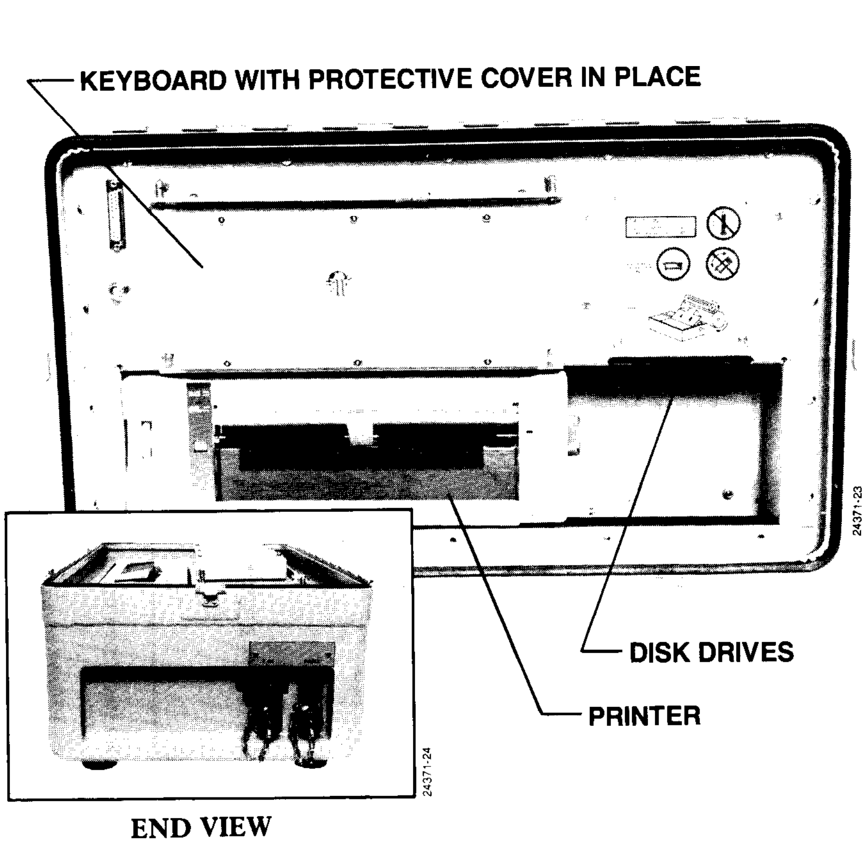


Figure 2—Recording unit

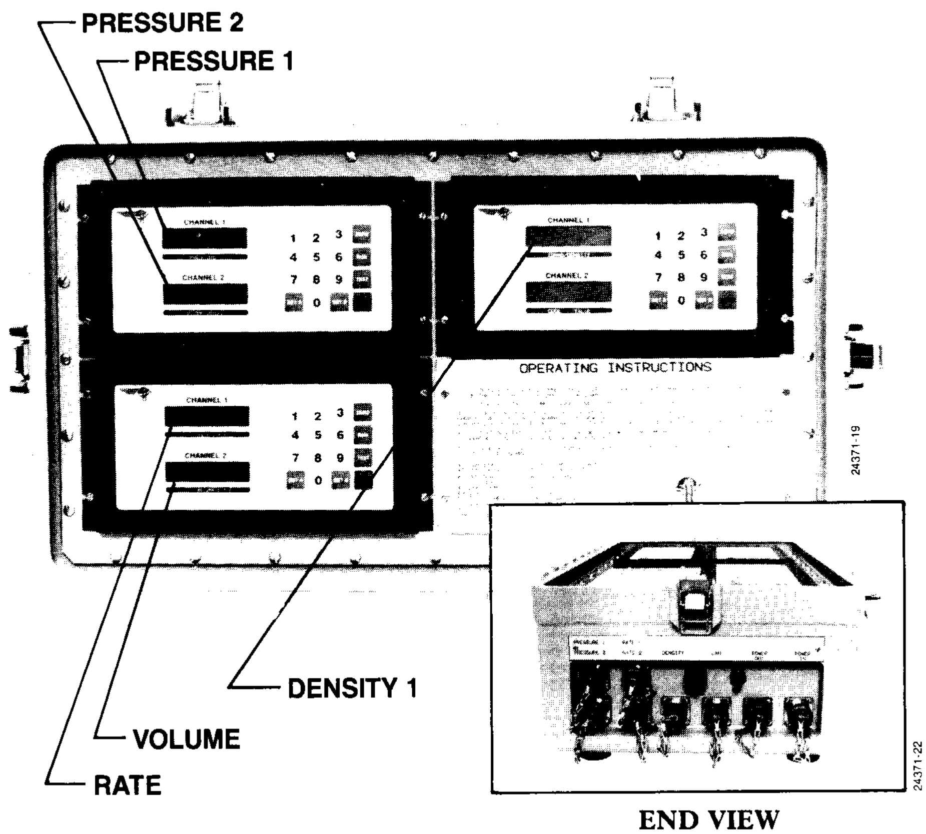


Figure 3—Display unit

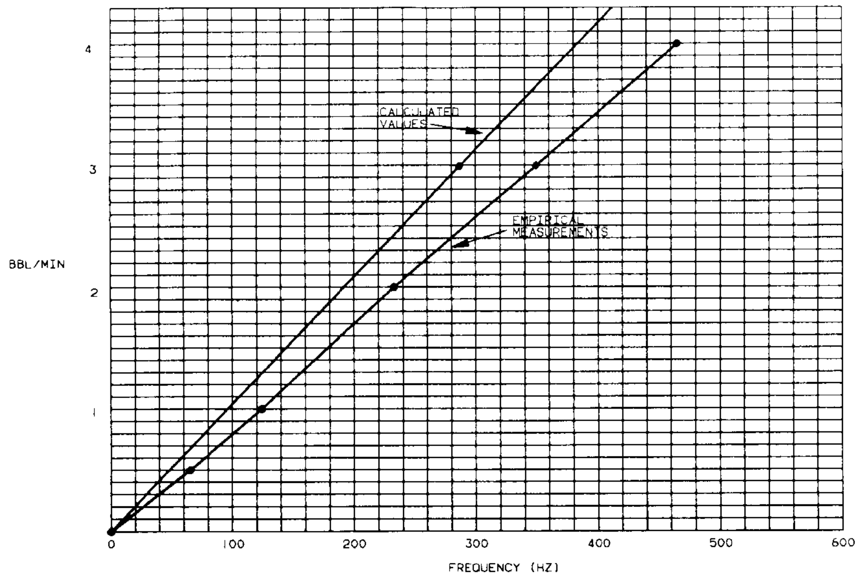


Figure 4—Pump shaft RPM data

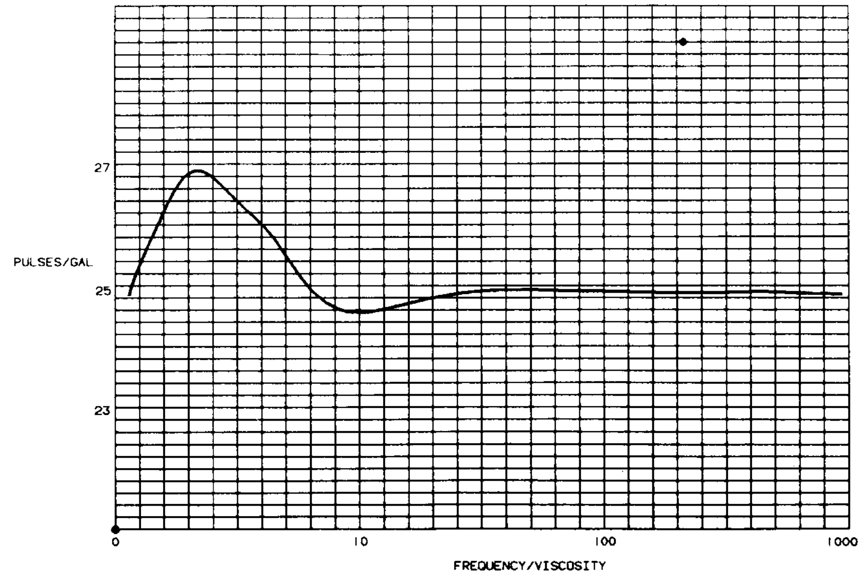


Figure 5—Flowmeter viscosity vs frequency curve

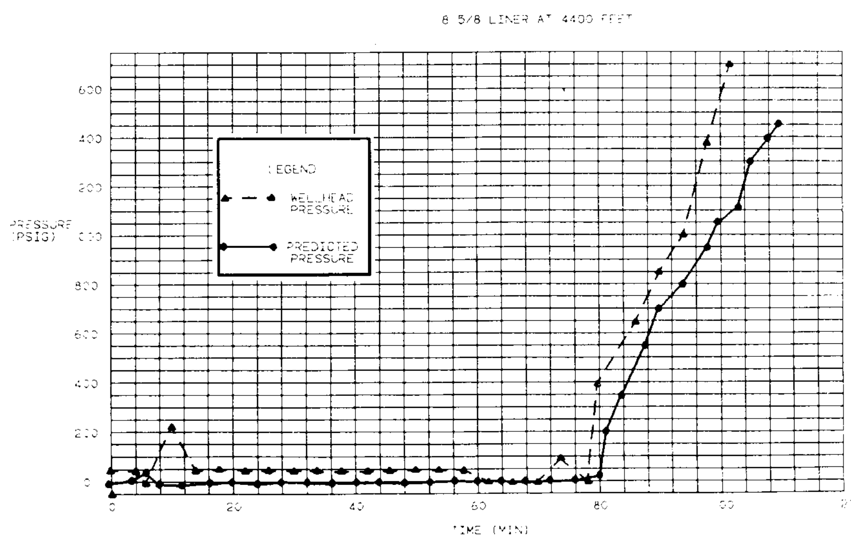
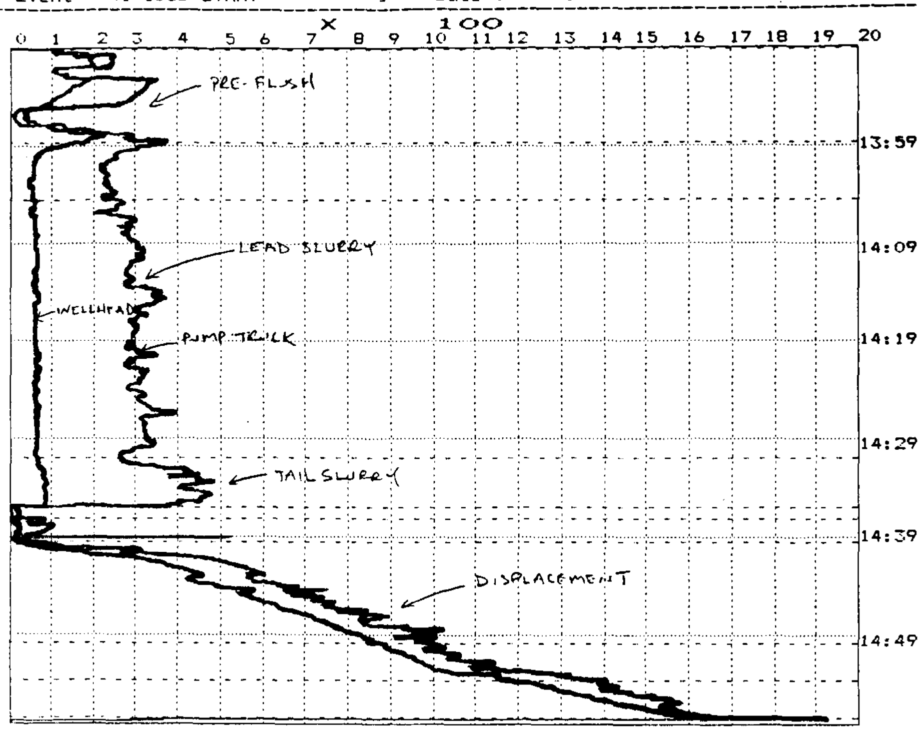


Figure 6—Case 1 - Predicted vs. actual wellhead pressure

Event - 41 [JOB START] Date 07/14/1986 - Time 13:49:39



Searching for events.
Events are marked on the chart by:

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**************************** Event Summary ***************************
Event - 49 [SPACER 1          ]    Date 07/14/1986 - Time 13:49:57
Event - 53 [SPACER 2          ]    Date 07/14/1986 - Time 14:06:34
Event - 47 [LEAD CEMENT       ]    Date 07/14/1986 - Time 14:16:45
Event - 47 [LEAD CEMENT       ]    Date 07/14/1986 - Time 14:16:46
Event - 51 [TAIL CEMENT       ]    Date 07/14/1986 - Time 15:02:20
Event - 55 [TOP PLUG DROPPED  ]    Date 07/14/1986 - Time 15:10:55
Event - 59 [DISPLACEMENT      ]    Date 07/14/1986 - Time 15:12:48
Event - 61 [PLUG LANDED       ]    Date 07/14/1986 - Time 15:16:41
Event - 59 [DISPLACEMENT      ]    Date 07/14/1986 - Time 15:35:44
Event - 59 [DISPLACEMENT      ]    Date 07/14/1986 - Time 15:42:36
Event - 61 [PLUG LANDED       ]    Date 07/14/1986 - Time 15:49:34
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Figure 7—Case 1 - Actual wellhead vs. pump truck pressure

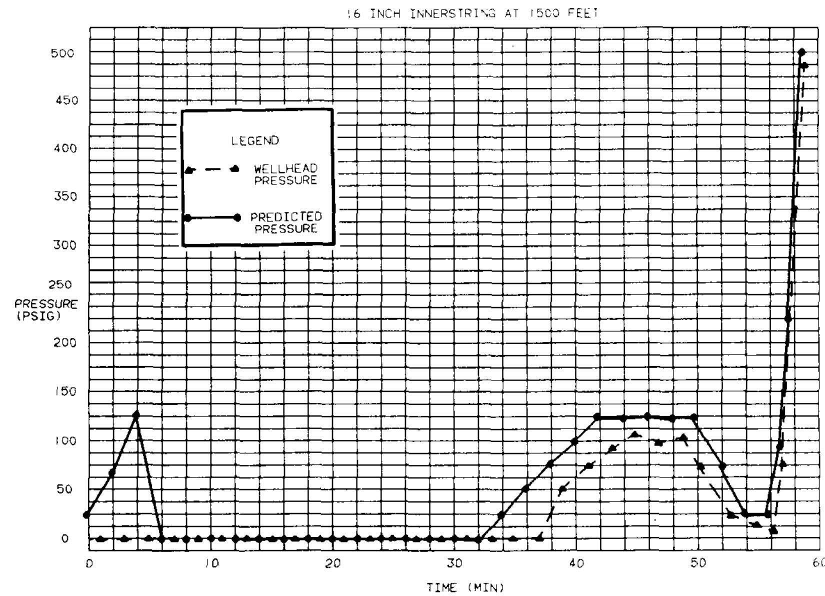
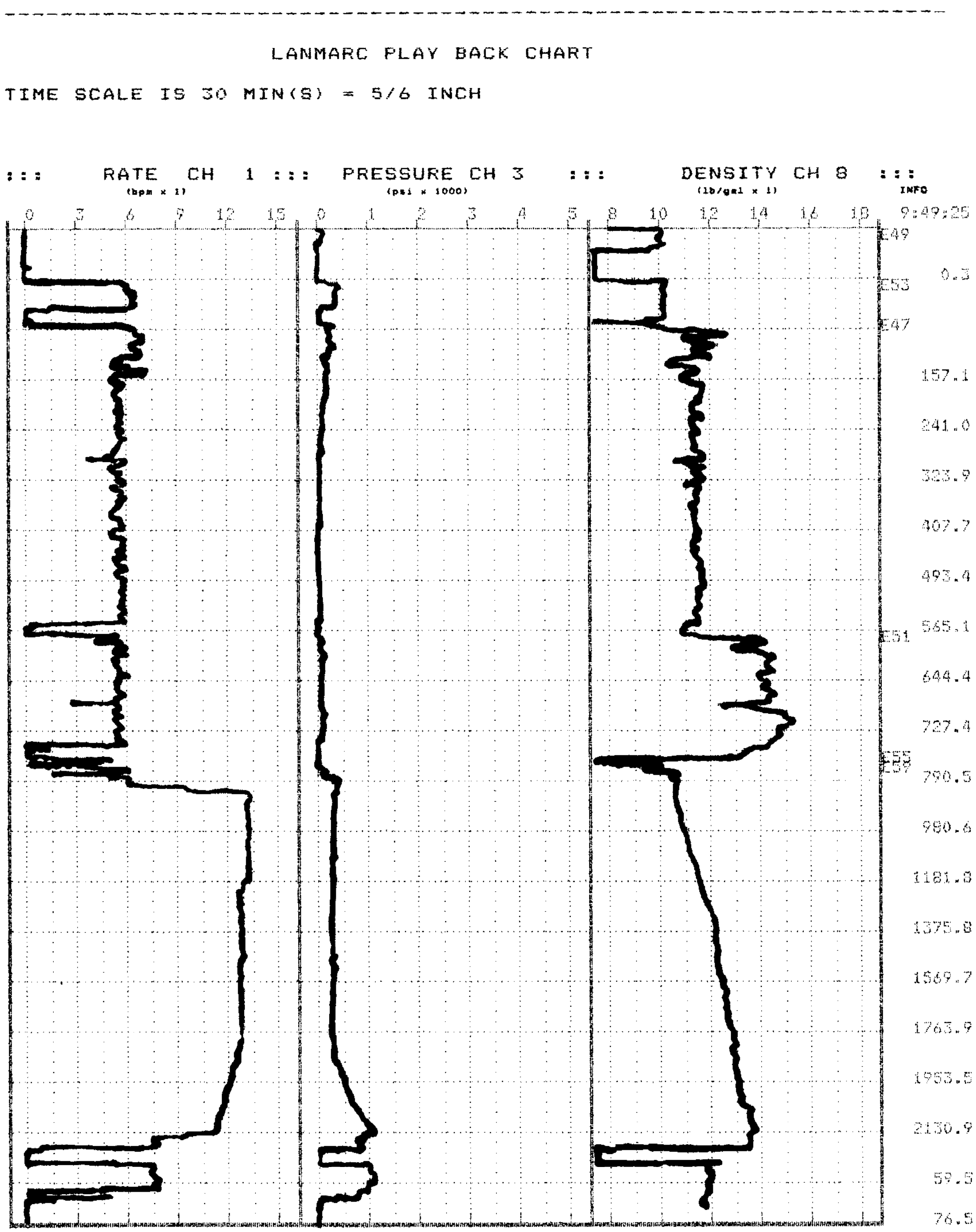


Figure 8—Case 2 - Predicted vs. actual wellhead pressure



JOB SUMMARY:

START TIME 9:49:25 DATE : 1/11/87

event SUMMARY:

event 41	9:49:25	JOB START
event 49	9:49:38	SPACER 1
event 53	10: 6: 0	SPACER 2
event 47	10:16:58	LEAD CEMENT
event 51	11:50:17	TAIL CEMENT
event 57	12:26:43	BOTTOM PLUG
event 55	12:26:58	TOP PLUG DROP
event 59	12:28:40	DISPLACEMENT
event 69	14:41:49	JOB END

STOP TIME 14:41:49 DATE : 1/11/87

DURATION 4:52:24

TOTAL VOLUME 76.53

RATE CHART 1 AVERAGE 7.60 BPM

PRESSURE CHART 2 AVERAGE 271.81 PSI

DENSITY CHART 3 AVERAGE 11.50 PPG

Figure 9—Case 3 - System rate, pressure and density chart