MICROPROCESSOR CONTROLLED BLENDER USED TO PROVIDE RAMPING SAND CONCENTRATION SCHEDULE DURING FRACTURING JOBS IN WEST TEXAS

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ABSTRACT

A standard fracturing blender retrofitted with a microprocessor controlled proppant delivery system has been operating in the Odessa, Texas area since May 15, 1986. The speed and control capabilities of the system's microprocessor has allowed fracturing operations incorporating non-standard "ramping" sand concentration schedules to be routinely performed with this blender. Fracturing operations with "stair step" sand concentration schedules have also been completed with this blender.

Subject paper presents a case history of fracturing operations performed in West Texas with a microprocessor controlled fracturing blender. Pre-job planning, system operation and blending capabilities of the blender are also discussed.

Case history documentation for fracturing operations with ramping sand concentration schedules is presented in the form of strip chart data collected during these operations. Documentation is also presented for a fracturing operation with a stair step sand concentration schedule.

INTRODUCTION

The classic sand concentration schedule consists of multiple, unequal volume stages of sand-laden fracturing fluid. Previously, fracturing operations were limited to the classic "stair step" sand concentration schedule due to control limitations of the fracturing blender used during these operations. The introduction of a fracturing blender equipped with a microprocessor controlled proppant delivery system has removed these limitations.

Fracturing operations with non-standard ramping sand concentration schedules have been performed routinely in West Texas with a blender equipped with a microprocessor controlled proppant delivery system. A typical sand concentration strip chart recorded during one of these operations is shown in Fig. 1. The linear increasing portion of Fig. 1 is referred to as the sand concentration ramp. The constant sand concentration stage following the ramp is referred to as the tail-in or final stage for the fracturing operation. It should be noted that the tail-in stage is usually, but not always, performed during a fracturing operation designed with a sand concentration ramp.

PRE-JOB CALCULATIONS AND PLANNING

Pre-job calculations are performed upon receiving the approved stimulation design for a fracturing operation. These calculations are essential for determining whether or not the blender has the capabilities to perform the fracturing operation as designed. These calculations are also required for the optimum tuning of the blender's automatic proppant delivery system. Pre-job calculations will include determining:

1. Maximum flow rate of clean base fluid to be expected during the fracturing operation.

2. Minimum flow rate of clean base fluid to be expected during the fracturing operation.

3. Maximum sand delivery rate to be expected during the fracturing operation.

4. Minimum sand delivery rate to be expected during the fracturing operation.

To perform a fracturing operation as designed, the minimum delivery rate of the blender's proppant delivery system must be less than the calculated minimum proppant delivery rate expected during the fracturing operation. The maximum delivery rate of the blender's proppant delivery system must also be larger than the calculated maximum proppant delivery rate expected during the fracturing operation. If either of these statements is false, the fracturing operation can not be performed as designed with the blender. In such a case the sand concentration schedule must be altered slightly so that the blender can perform the fracturing operation.

Two flowmeters with different operating ranges are installed on a blender equipped with a microprocessor controlled proppant delivery system (Fig. 2). Prior to the start of a fracturing operation, the system operator must choose which flowmeter is to be used by the proppant control system during the fracturing operation. The operator will choose the flowmeter which is most accurate for calculated minimum and maximum base fluid flow rate expected during the fracturing operation. Correct flowmeter selection is essential if the automatic proppant delivery system is to have optimized control during the fracturing job.

SYSTEM DESIGN AND OPERATION

The microprocessor controlled proppant delivery system was designed so that it could be easily retrofitted to existing field proven blenders. Only minor modifications were made to the blender so that the proppant delivery system of the blender could be controlled automatically with a field ruggedized microcomputer. An equipment schematic of the automatic proppant delivery system is shown in Fig. 2.

Proppant metering screws of a blender retrofitted with the automatic proppant delivery system can be controlled with either the standard manual hydraulic control valves of the blender or with the electrohydraulic control valves added to the blender as part of the control system retrofit (Fig. 2). These electrohydraulic valves are controlled by electrical signals which can be generated by either the remote control box during manual operation or by the control system microcomputer during automatic operation. The manual control valves mounted on the blender are currently used only in a manual backup capacity in case of an electrohydraulic valve failure.

Whenever the proppant delivery system is operated automatically, the control system microcomputer will execute control software to maintain the sand concentration in the fluid exiting the fracturing blender at a given sand concentration setpoint. The sand concentration of the fracturing fluid is held constant by the control software at the given setpoint by maintaining a constant ratio of proppant to clean fluid being delivered into the blender mixing tub. Major steps taken by the control system setpoint subprogram to maintain this ratio are as follows:

1. Collect input data from the fracturing blender on the clean fluid delivery rate and proppant delivery rate into the blender mixing tub.

2. Calculate required sand delivery rate to maintain the sand concentration of the fracturing fluid at the required sand concentration setpoint.

3. Compare the calculated sand delivery rate to the measured sand delivery rate and adjust the proppant delivery system until the two values are equal.

4. Repeat steps 1-4 to maintain the sand concentration of the fracturing fluid exiting the blender at the value held in the sand concentration setpoint register.

The setpoint subprogram of the system control software will maintain the sand concentration of the fracturing fluid at the value held in the setpoint register indefinitely until the value is changed to a new setpoint. New setpoint values can be entered into the setpoint register manually by the system operator or by the system microcomputer during operation of the automatic proppant delivery system. When operating the system during a fracturing operation with a stair step sand concentration schedule, the system operator will manually enter the sand concentration setpoints during the operation. When the system is used during a fracturing job with a ramping sand schedule, the microcomputer will enter the setpoints automatically throughout the fracturing operation.

HISTORY OF FRACTURING OPERATIONS

The blender equipped with the microprocessor controlled proppant delivery system has been used predominately during fracturing operations with difficult to perform ramping sand concentration schedules. The case history information presented for the blender is therefore exclusively for fracturing operations which were performed with ramping sand concentration schedules. Documentation is, however, presented for one fracturing operation which utilized a stair step sand concentration schedule. This fracturing operation was performed with a blender retrofitted with an identical microprocessor controlled proppant delivery system operating in the Laredo, Texas area.

Case 1

Fig. 1 documents a sand concentration strip chart recorded during a fracturing operation with a ramping sand concentration schedule. The starting sand concentration setpoint for the ramping sand schedule was 1 lb/gal (119.8 kg/m³) and the ending sand concentration setpoint 6 lb/gal (719.0 kg/m³). The maximum pumping pressure during this operation was 1600 psi (110.3 x 10^2 kPa), the downhole flow rate 40 bbl/min (106.0 x 10^{-3} m³/s), and the overall pumping time for sand-laden fluid 9 1/2 minutes.

As Fig. 1 shows, a nearly perfect sand concentration ramp followed by a tail-in stage was performed during the fracturing operation. The ramp portion of this operation was executed in 5 minutes, and the tail-in stage in 4 1/2 minutes. Maximum deviation from the sand concentration setpoint during the entire fracturing operation was .15 lb/gal (18.0 kg/m³). Transition between the ramping portion of the sand concentration schedule and the tail-in stage, as Fig. 1 shows, was very smooth, without setpoint overshooting.

Case 2

A fracturing operation with a 14 minute sand concentration ramp followed by a 3 minute tail-in stage is shown in Fig. 3. The starting sand concentration setpoint for this ramping operation was 1/2 lb/gal (59.9 kg/m³) and the ending sand concentration setpoint 4.5 lb/gal (539.2 kg/m³). The average downhole flow rate during the fracturing operation was 36.5 bbl/min (96.7 x 10^{-3} m³/s) and the maximum treating pressure 1200 psi (82.7 x 10^2 kPa). Sand-laden fluid pumping time during this fracturing operation was 17 minutes.

The ramping portion of the fracturing job, as Fig. 3 shows, is linear with minor deviations from the straight line ramp design. The tail-in stage of this operation was completed with an average measured sand concentration value of 4.65 lb/gal (557.2 kg/m³). This average measured sand concentration value deviates from the final stage sand concentration setpoint by only .15 lb/gal (18.0 kg/m³). This minor deviation would have been reduced to a smaller value if the pumping time for the final stage had been longer, thus allowing the system operator time to fine tune the control system.

Case 3

A fracturing operation which consisted of a sand concentration ramp followed by a very small tail-in stage is shown in Fig. 4. The stimulation design for this operation consisted of a ramping sand schedule with a beginning sand concentration setpoint of 1 lb/gal (119.8 kg/m³) and a final sand concentration of 6 lb/gal (719.0 kg/m³). The downhole flow rate during this operation was 20 bbl/min (53.0 x 10^{-3} m³/s) and the maximum treating pressure 2200 psi (151.7 x 10^2 kPa). Sand-laden fluid was pumped during the operation for 9 1/4 minutes.

The tail-in stage during the operation documented in Fig. 4 consisted of 317 gal of 6 lb/gal (719.0 kg/m³) sand-laden fracturing fluid. This stage, lasting only 22 seconds, is undistinguishable in the strip chart data recorded during the operation. The ramping portion of the operation, as Fig. 4 shows, is linear with very little deviation from a perfect straight line ramp. The ramp portion of the fracturing operation lasted approximately 9 minutes.

Case 4

The chart documented in Fig. 5 is a portion of the strip chart recorded during a fracturing job with a stair step sand concentration schedule. Maximum pumping pressure during this job was 8000 psi (551.6×10^2 kPa) and the downhole flow rate 30 bbl/min (79.5×10^{-3} m^3/s). The stimulation design for this operation called for 2, 4, 6, 8, 10, and 12 lb/gal stages of sand-laden fracturing fluid. Sand concentration setpoints for these stages were changed during the course of the actual operation by the company man to 2, 4.2, 6.3, 9.0, 11, and 14 lb/gal.

As the strip chart in Fig. 5 shows, almost perfectly square step changes in sand concentration were performed when changing stages during this fracturing operation. The time required to complete each stage change was typically less than 60 seconds. Sand concentration of the fracturing fluid, as Fig. 5 shows, was held by the automatic proppant delivery system constant during each stage with minor deviation for the sand concentration setpoint for the stage.

BLENDING CAPABILITIES AND DESIGN FEATURES

1. A microprocessor controlled proppant delivery system, when installed on a standard fracturing blender, automatically adjusts the blender sand delivery system to maintain the sand concentration of the fracturing fluid exiting the fracturing blender at the required setpoint regardless of fluctuations in the downhole flow rate.

2. Large step changes in sand concentration between stages of a fracturing operation utilizing a stair step sand concentration schedule can be performed quickly with a blender equipped with an automatic proppant delivery system. The probability of overshooting the new sand concentration setpoint is also drastically reduced when such a system is used.

3. The control system will automatically control the blender sand delivery system without operator intervention throughout a fracturing operation utilizing a ramping sand concentration schedule. The system operator is required only to enter job design data into the control system prior to the start of the fracturing operation.

4. A smooth curvelinear sand concentration schedule can be performed during a fracturing operation if the curvelinear sand schedule is approximated with multiple ramping sand concentration schedules. A good approximation to most curvelinear schedules can be made with five or fewer ramping schedules. An example of an approximation for a curvelinear sand concentration schedule is shown in Fig. 6.

5. A fracturing blender retrofitted with an automatic proppant delivery system retains the mixing and pumping capabilities it had prior to being retrofitted.

6. The sand delivery system of a blender equipped with an automatic proppant delivery system can be manually or automatically operated at a remote distance up to 250 ft (76.2 m) from the fracturing blender.

7. The electrohydraulic valves used by the microprocessor controlled proppant delivery system are installed in parallel across the standard manual hydraulic control valves. This plumbing arrangement allows for manual backup control in case of electrohydraulic valve failure.

CONCLUSIONS

1. A fracturing blender equipped with a microprocessor controlled proppant delivery system can be used routinely to perform non-standard ramping sand concentration schedules which are very difficult to execute with a standard blender not equipped with an automatic proppant delivery system.

2. The quality of a fracturing operation designed with a stair step sand concentration schedule is improved if a fracturing blender equipped with an automatic proppant delivery system is used during the operation.

3. Fracturing operations designed with smooth curvelinear sand concentration schedules can be performed with a blender equipped with a microprocessor controlled proppant delivery system.

SI METRIC CONVERSION

bbl/min	x 2.649788	x 10^{-3}	=	m^3/s
ft	x 3.048	x 10^{-1}	=	m
gal	x 3.785412	x 10^{-3}	=	m^3
lb	x 4.535924	x 10^{-1}	=	kg
lb/gal	x 1.198264	x 10^{2}	=	kg/m^3
min	x 60		=	s
psi	x 6.894757		=	kPa

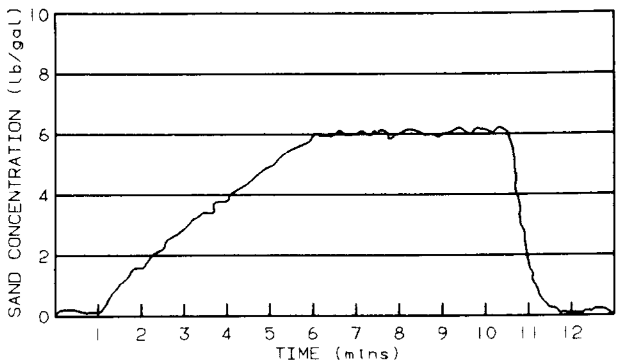

Figure 1—Sand concentration strip chart for Case 1

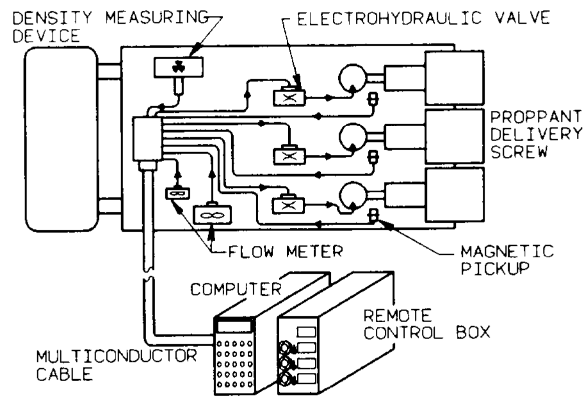

Figure 2—Equipment schematic

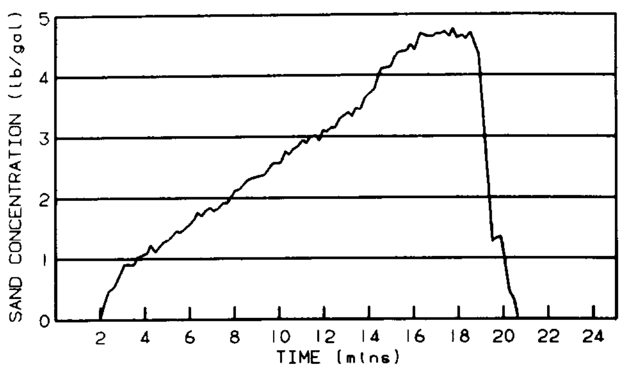

Figure 3—Sand concentration strip chart for Case 2

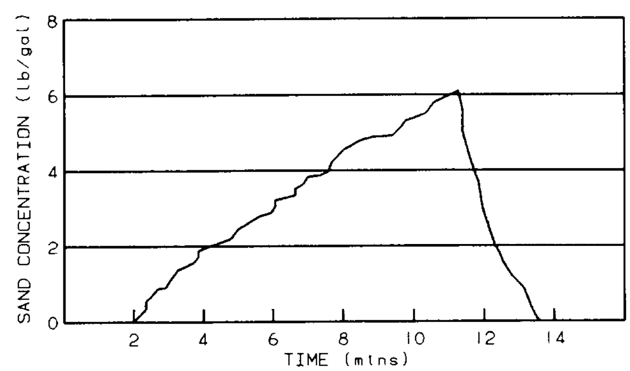

Figure 4—Sand concentration strip chart for Case 3

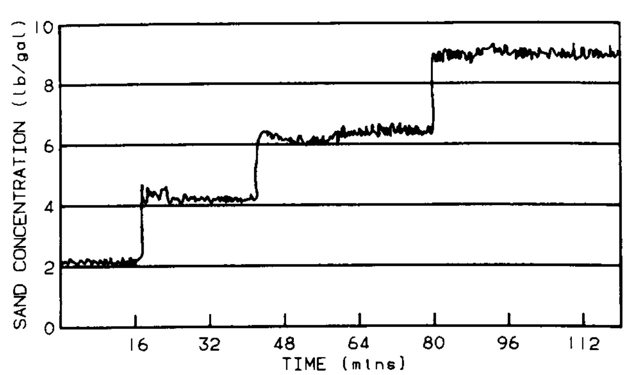

Figure 5—Sand concentration strip chart for Case 4

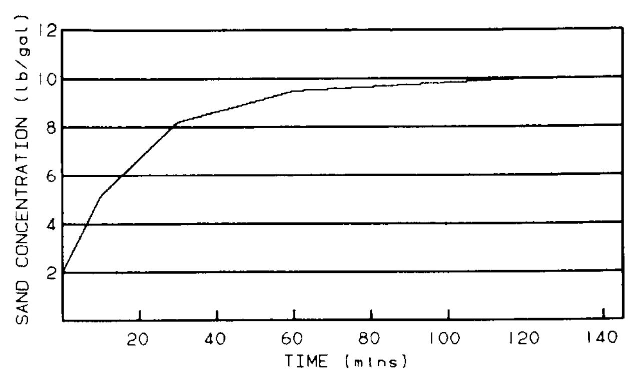

Figure 6—Example of curvilinear sand concentration schedule