AN IMPROVED FOAM FRACTURING PROCESS

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INTRODUCTION

A recurring problem in foam fracturing is sand suspension; i.e., the suspension of high sand concentrations in the liquid phase of a foam frac system. A process has been developed which enables the liquid phase to be pumped directly from the blender to the high-pressure pumps without recirculating to suspend high sand concentrations.

This process for foam frac is improved by using a unique gel-gel breaker system for the liquid portion used in generating the foam. The advantage of this system is that more sand may be carried in the liquid portion, which means that more sand can be delivered downhole, which in turn delivers more sand to the fracture, resulting in more of the created fracture being propped.

The liquid portion of the fluid is divided into two portions. The main liquid portion which carries the sand is modified by hydrating a cellulose-type polymer in water to form a viscous gel. The viscosity of this gel is such that high sand concentrations can be carried without recirculation. The other smaller portion carries a foaming agent and a gel breaker. When the two liquids are combined, the viscosity of the gel breaks immediately. Nitrogen gas is then added downstream to generate the foam as shown in Fig. 1.

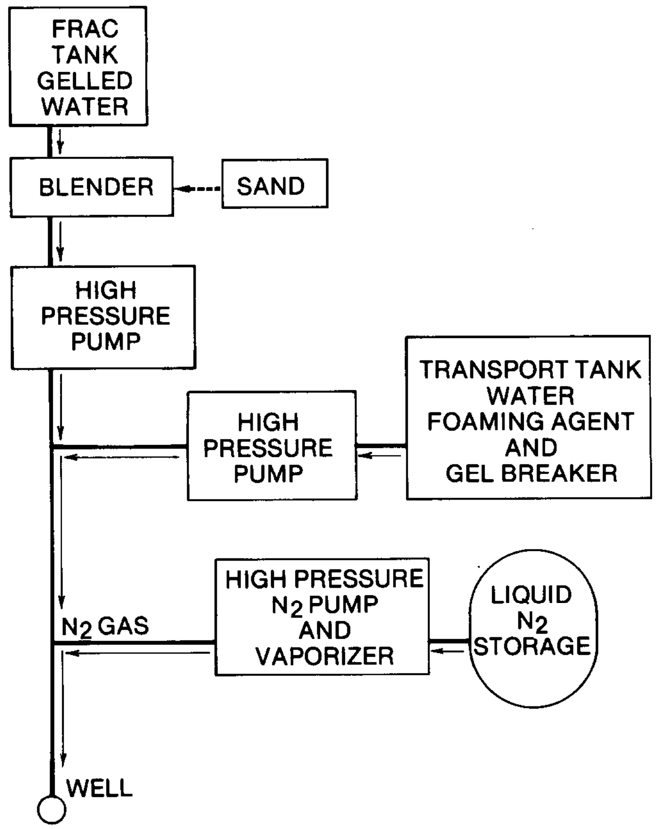

FIG. 1 – EQUIPMENT SET UP FOR FOAM GENERATION

LABORATORY DATA

Laboratory experiments were made to determine the properties of the gel-gel breaker system and of the foam made with the broken gel. The gel portion was made by hydrating a cellulose-type polymer at a concentration of 60 lb/1000 gal. of water. A gel breaker was added to the other portion containing the foaming agent. The two liquid portions were mixed with a laboratory stirrer and the initial viscosity of the gel, measured on a Fann 35 rotational viscometer at 300 rpm, was 89 cp. Five seconds later, the viscosity was 7 cp. As can be seen from this, the gel breaker is effective and almost instantaneous.

Using the broken gel, foam was generated in a laboratory apparatus (Fig. 2) consisting of a small pump for the broken gel liquid portion, a nitrogen gas cylinder with a pressure regulator, flowmeters for both streams, and a small packed cell. The packed cell was necessary to generate a uniform foam on this small scale. The viscosities of the foam generated with the broken gel and a foam generated with water were measured and compared on a Fann 35 rotational viscometer. As can be seen from Table 1, the foam generated with the broken gel had more viscosity than the same quality foam generated with water. For example, a foam of 75 quality (percent gas by volume) generated from broken gel has a viscosity of 123 cp at 100 sec^{-1} and a foam of 89 quality generated from water has a viscosity of 102 cp at 100 sec^{-1}. The generated foam was collected and observed until all the foam had broken. The foam from both systems broke in about 20 minutes, leading to the conclusion that the broken gel foam system breaks out in the same time as a water foam system.

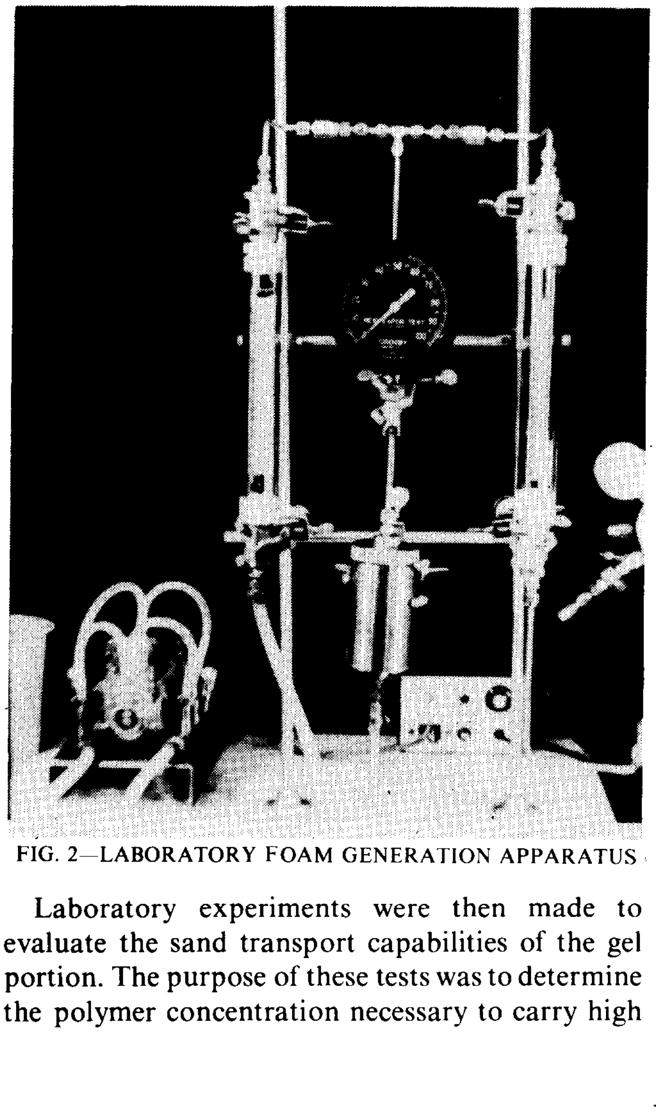

FIG. 2—LABORATORY FOAM GENERATION APPARATUS

Laboratory experiments were then made to evaluate the sand transport capabilities of the gel portion. The purpose of these tests was to determine the polymer concentration necessary to carry high sand concentrations directly from a blender to high-pressure pumps without having to recirculate the fluid to suspend the sand. The apparatus used was a flow loop of 1-in. pipe with a plexiglass section for observation. The first series of sand transport tests were made at a fluid velocity of 3 fps which

TABLE 1 RHEOLOGY OF FOAM FRAC MADE WITH BROKEN GEL

Quality	n'	k'	V(100 sec^{-1})
84	.43	.10	370
83	.43	.09	333
80	.48	.05	233
79	.52	.04	224
75	.54	.02	123

MADE WITH WATER

Quality	n'	k'	V(100 sec^{-1})
92	.43	.05	185
90	.49	.03	146
89	.50	.02	102

represents the fluid velocity of the liquid portion of a 75 quality foam at a rate of 20 BPM. First, a sand concentration of 2 lb of 20-40 mesh sand per gal. of water was observed. As seen in Fig. 3, most of the sand was static on the bottom of the pipe, the remainder was moving in the middle of the pipe and clear fluid was moving in the top third of the pipe. It is obvious that water at low velocities is inadequate for transporting sand. Next, 40 lb of polymer per 1000 gal. was added to the water. From Fig. 4, it can be seen that the sand was more evenly distributed with no static portion. Sand concentration was increased to 4 ppg and then to 6 ppg. In each case, the sand was still moving and was evenly distributed. These examinations show that a 40 lb/1000 gal. gel is adequate to suspend up to 6 ppg of 20-40 sand.

The next series of tests were made using 10-20 mesh sand at a fluid velocity of 3 fps. Two pounds of 10-20 mesh sand per gal. of water were added as shown in Fig. 5. As in the case of the smaller-mesh sand, a large portion of the sand was static on the bottom, a small portion of the sand moved in the middle, and water flowed on the top. Again, it is clear that water at low velocities is a poor sand-carrying medium. As before, polymer was added at 40 lb/1000 gal., which caused all the sand to begin moving. Sand concentration was increased to 4 lb of 10-20 sand per gal. and all the sand was still moving with no static portions. Polymer concentration was increased to 60 lb/1000 gal., and sand concentration

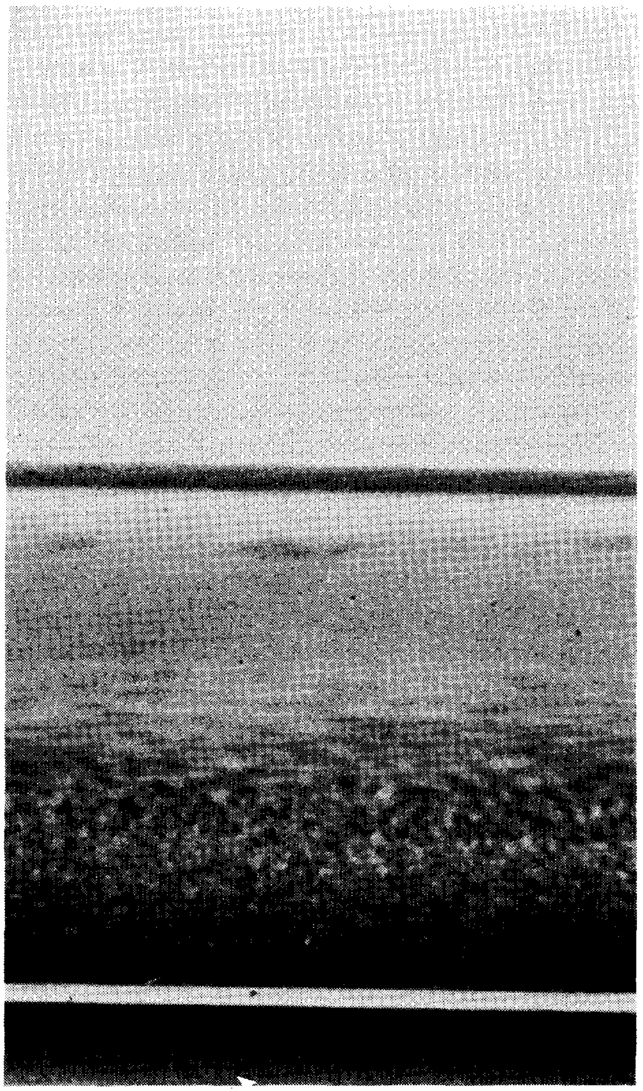

FIG. 3—TWO LB PER GAL. OF 20-40 MESH SAND IN WATER.

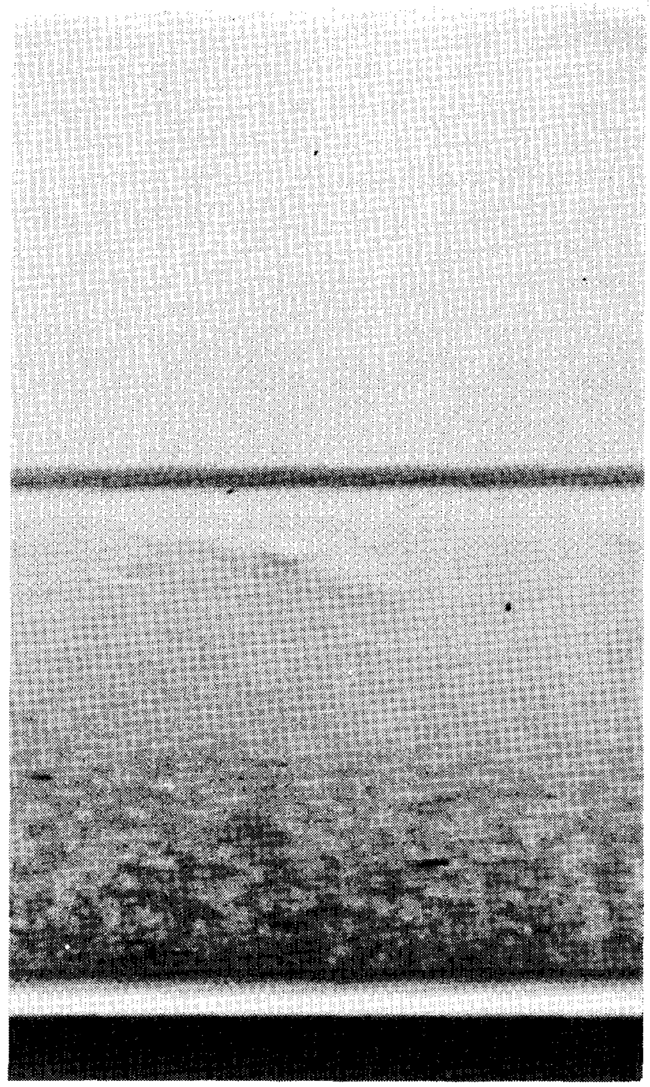

FIG. 4—TWO LB PER GAL. OF 20-40 MESH SAND IN 40 LB PER 1000 GAL. OF POLYMER

was increased to 6 lb of 10-20 sand per gal. Despite the high concentration, the sand was suspended and moving. Polymer concentration was increased to 80 lb/1000 gal. and sand concentration was increased to 8 lb of 10-20 sand per gallon. As Fig. 6 shows, the sand was suspended and moving.

Another series of sand transport tests were made at a lower fluid velocity of 1.5 fps corresponding to the liquid portion of a 75 quality foam at a rate of 10 BPM. Using a 60-lb gel, 6, 8, and 10 lb of 20-40 mesh sand per gal. were tested. In all tests the sand was suspended and moving. The results, using 10 lb of sand, are shown in Fig. 7. The tests were repeated using 10-20 mesh sand in an 80-lb gel at concentrations of 6 and 8 ppg. In both tests, the sand was well-suspended and moving.

From these series of tests, sand concentration-polymer concentration loading schedules for the gel portion of the liquid phase were developed, as shown in Table 2.

FIELD EXPERIMENTS

Three controlled experiments were run at field locations with the same type of equipment and equipment hookup that is normally used on an actual frac job. Typical rates and pressures were simulated, as were the sand size and concentration. Through close observation and measurements of sand concentration in samples taken at critical points in the experiments, both limitations and abilities of a fluid to transport sand through the flow

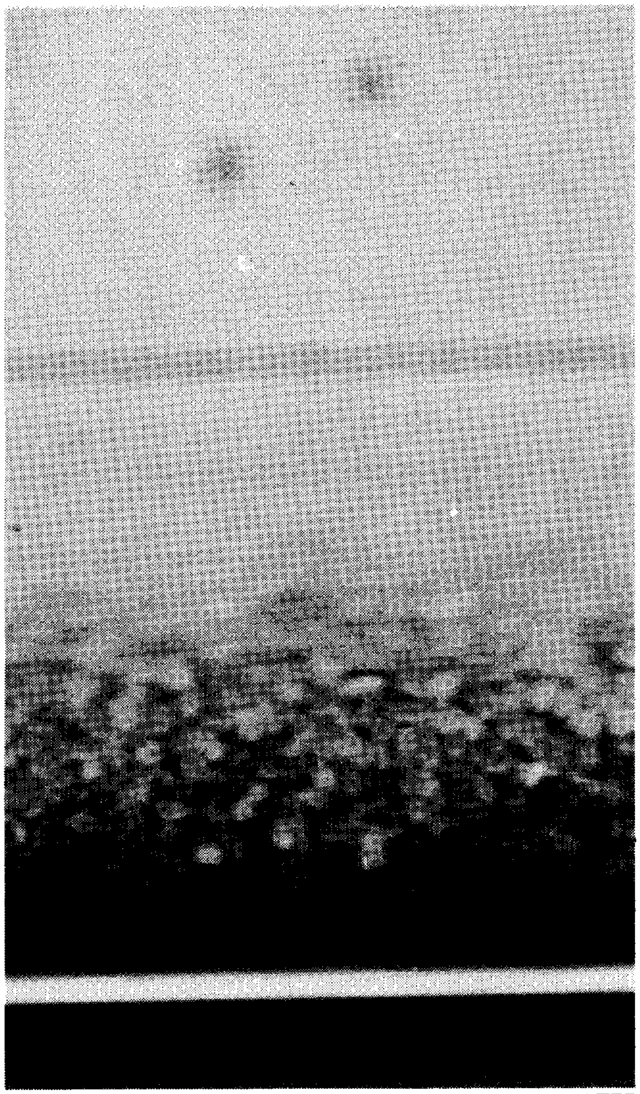

FIG. 5—TWO LB PER GAL. OF 10-20 MESH SAND IN WATER

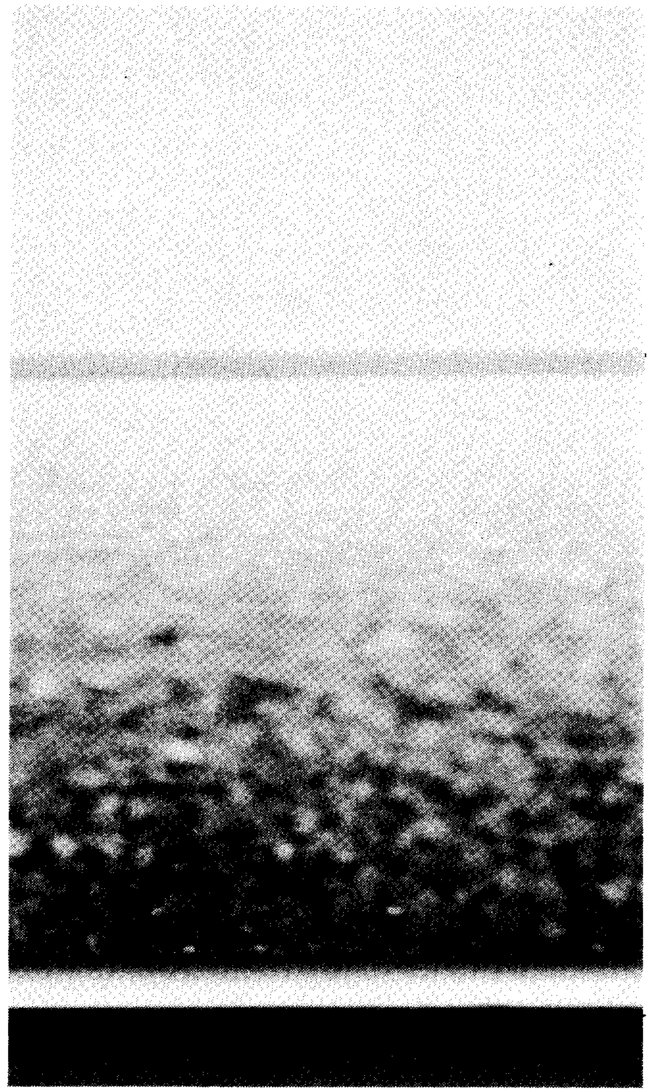

FIG. 6—EIGHT LB PER GAL. OF 10-20 MESH SAND IN 40 LB PER 1000 GAL. OF POLYMER

channels in surface equipment could be evaluated.

In the first experiment, the equiment was arranged in the manner shown in Fig. 8. The blender was modified so that fluid and sand could be recirculated at high rates. In conventional fracturing, the fluid is not recirculated; rather, it is fed directly to triplex pumps with a blender, then pumped downhole. In this experiment, one end of the suction manifold of the triplex pump was connected to the blender with a 4-in. hose. A 3-in. hose was connected to the other end of the suction manifold and discharged back into the blender tub. Sand (20-40 mesh) and water were combined at a ratio of 6 ppg. (This is a typical concentration that is necessary to obtain a sand concentration of about 1.5 ppg downhole.) The slurry was discharged from the blender tub at 30 BPM and re-entered the tub at 26 BPM. The remaining 4 BPM were pumped by the triplex pump through the discharge line. A 1/4-in. bean was placed in this line so that typical wellhead pressures could be duplicated. Samples of fluid from the discharge of the triplex were collected and the sand concentration in each was determined. Table 3 gives the results from this experiment.

TABLE 2 — LOADING SCHEDULE FOR POLYMER

Sand Size Mesh	Sand Concentration at blender lb/gal	Polymer Concentration lb/1000 gal
20-40	0-6.0	40
20-40	6.1-10.0	60
10-20	0-4.0	40
10-20	4.1-6.0	60
10-20	6.1-8.0	80

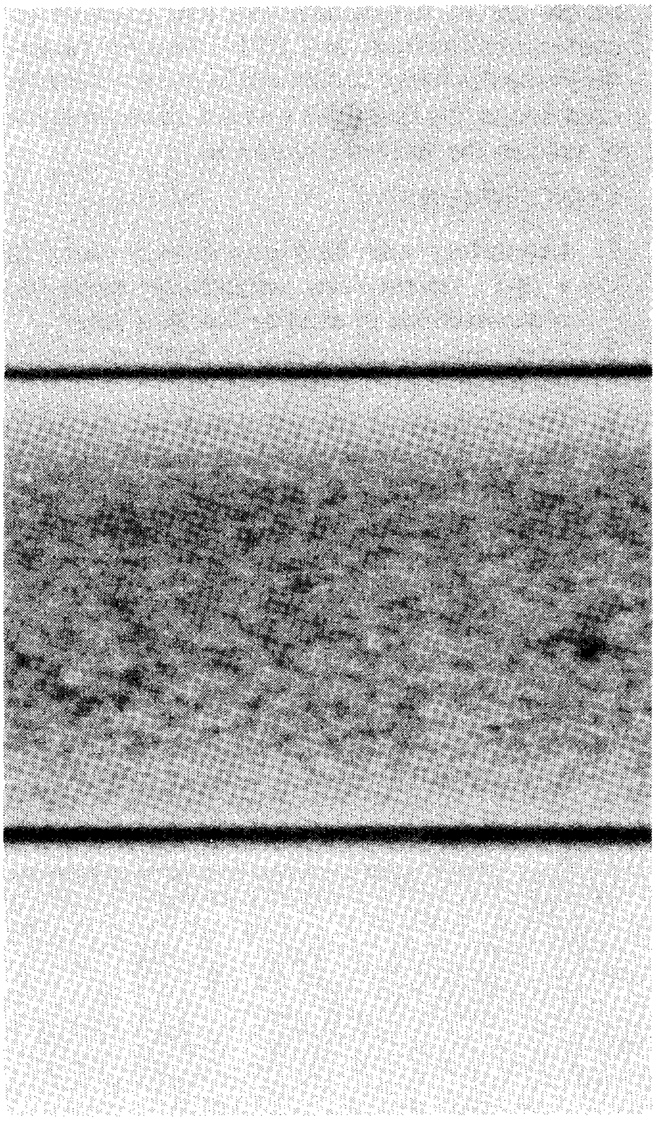

FIG. 7—TEN LB PER GAL. OF 20-40 MESH SAND IN 80 LB PER 1000 GAL. OF POLYMER

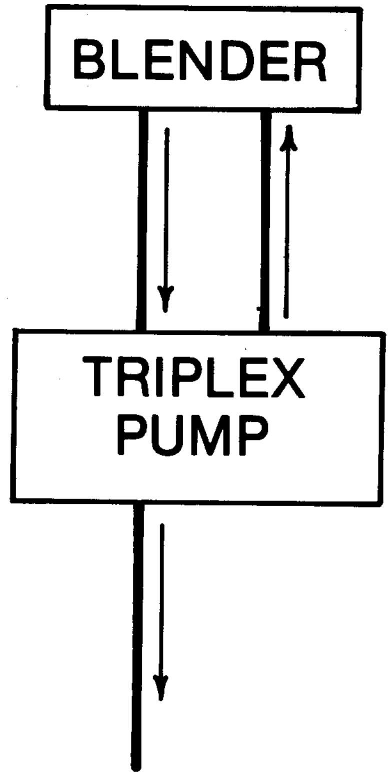

FIG. 8—EQUIPMENT SET UP FOR FIRST FIELD EXPERIMENT

TABLE 3

Sample No.	Input Concentration lb/gal	Time min	Output Concentration lb/gal
1	6	10	5.4
2	6	15	5.8
3	6	20	6.2

In the second experiment, fluid was circulated through two triplex pumps. Figure 9 shows a schematic drawing of the equipment hookup for this series of tests. In the first test, 10-20 sand was used and added at 6 ppg. The initial rate was 30 BPM from the blender, and total discharge rate from the two triplex pumps was 5 BPM. It was soon evident that sand was being accumulated in the system because, at a constant throttle setting on the motors which supplied power to the circulating pumps, the rate of circulation steadily declined. The rate was allowed to drop until a sandout started occurring at about 12 BPM. Although the average sand concentration was at least 6 ppg, samples taken from the pump discharge contained less than 3 ppg. This indicates that the proppant distribution in the circulating stream of water was not uniform. Since the pump cavities are fed with fluid from the upper part of the stream, they captured much less sand than that necessary to prevent sand accumulation. The results of this test correlated well with the laboratory observations of sand movement.

A third test made with field equipment was to determine what effects viscosity has on the fluid's sand-carrying ability through surface equipment. The fall rate of 10-20 sand through a gel containing 60 lb/1000 gal. of a cellulose polymer was less than one one-hundredth that of the settling rate of sand in water. The 10-20 mesh sand was added at 8 ppg

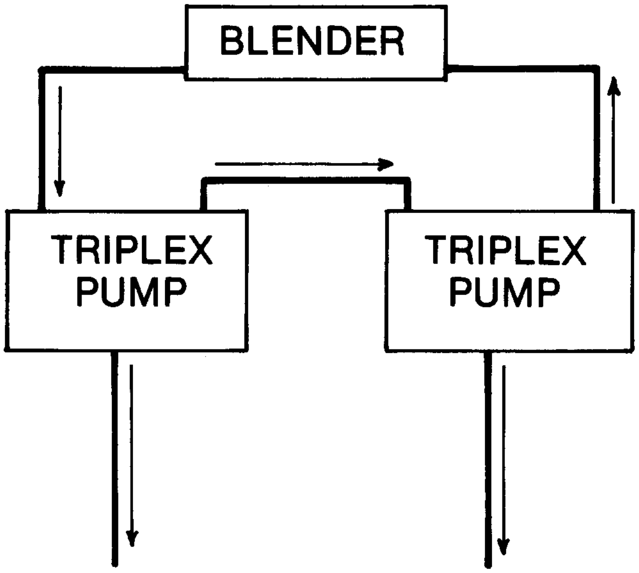

FIG. 9--EQUIPMENT SET UP FOR SECOND FIELD EXPERIMENT

to the gel in the blender tub and pumped in a conventional manner at 2 BPM. Samples taken at the pump discharge contained the proper amount of sand, indicating that there was not an accumulation of sand in the surface equipment.

CONCLUSIONS

1. Laboratory and field experiments show that a gel system can effectively move high concentrations of sand at low flow rates.
2. Sand concentration can be 8-10 ppg through the blender and triplex pumps.
3. The viscosity of the gel liquid can be broken almost instantaneously and used to generate a stable foam for fracturing.
4. The foam generated with the broken gel has higher viscosity than a water-generated foam, and breakout time is not affected.