SUCCESS OF A HIGH FRICTION DIVERTING GEL IN ACID STIMULATION OF A CARBONATE RESERVOIR, CORNELL UNIT, WASSON SAN ANDRES FIELD, WEST TEXAS

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ABSTRACT

The Cornell Unit is a 778.2 m^2 (1,923 acre) waterflood project in the Permian, San Andres, dolomite reservoir located in the Wasson Field, Yoakum County, Texas. The Unit currently consists of 66 producing wells and 26 injection wells. Production is approximately 1430.9 m^3 (9,000 barrels) of oil per day, 1367.3 m^3 (8,600 barrels) of water per day and 240,693.2 m^3 (8,500,000 cubic feet) of gas per day. Daily injection avarages 4133.7 m^3 (26,000 barrels) of water.

Early in 1979, it was recognized that a substantial reconditioning and infill drilling program was needed to prepare the Unit for a tertiary recovery project. Casing of open hole injectors and selected producers began in mid-1979 followed by infill drilling in early 1980.

Well stimulation by acid treatment is a routine completion procedure for these wells and, initially, the means to positively distribute the acid to the perforations was through the use of closely spaced straddle packers. Frequently, it was found that most of the perforations communicated while being acidized. Because of this communication, not only would other mechanical means of diversion within the well bore be unsatisfactory but diverting agents, which rely upon differential pressure temporarily sealing over the perforations, also would fail when the pressure across the perforation equalized. The need for a diverting agent which actually would enter the formation taking the acid and temporarily block it led to useage of a gelled and complexed guar gum material, commonly called High Friction Gel*. The success of High Friction Gel in achieving better overall distribution of the acid treatment is presented in this paper.

HIGH FRICTION GEL

High Friction Gel (HFG) is a fluid consisting of 36.3 kg (80 pounds) of guar gum, 11.3 kg (25 pounds) of borax and 1.4 kg (3 pounds) of enzyme per 3.8 m^3 (1,000 gallons) of fresh water.[1] Its active life is approximately 24 to 36 hours and consists of two phases. The first phase of approximately one hour is a period when the guar gum gel and the borate ions furnished by the borax are reacting, or

*U.S. Patent No. 3,948,325

References and Illustrations at end of paper.

complexing, and changing the flow characteristics of the mixture from those of a Newtonian fluid to a non-Newtonian, Bingham plastic fluid. The second phase of approximately 23 to 35 hours is a period when the mixture is truly a non-Newtonian, Bingham plastic fluid. Following the mixture's active life, it is completely broken by the enzyme breaker and ceases to exist as a gel.

During the period the HFG acts as a non-Newtonian, Bingham plastic fluid, the finite shear stress, or yield point, of the HFG must be exceeded in order for it to start to flow. In addition, high friction losses are experienced when moving the HFG because, after yield point, equal increments of additional shear stress will produce equal increments of a shear rate in proportion to the plastic viscosity of the HFG.

It can be seen, therefore, that HFG effectively would divert acid to less permeable parts of a formation if it could be placed in the more highly permeable portions of a formation. Then, the pressure necessary to break down less permeable parts of the formation could be reached before the yield point of the HFG in the permeable portions was exceeded and began to move.

ACID STIMULATION USING HIGH FRICTION GEL

The mixing and pumping equipment layout is shown in Figure 1. Before the job is begun, fresh water is drawn from the transport by pump A on the blender truck and discharged through the jet mixer below the hopper into the mixing tub. Guar gum is added at the hopper and drawn into the water by the jet mixer. The guar gum and water mixture is drawn from the mixing tub by pump B and discharged back into the transport. This blending is continued until the proper concentration of guar gum is attained for the given volume of gel to be used in the stimulation treatment. Meanwhile, the borax complexer and enzyme breaker are mixed with fresh water in a separate auxiliary mixing tank agitated by air. When all of the mixing is completed, the treatment is ready to begin.

The gel and the borax/enzyme mixtures do not come into contact until they are drawn into the main stimulation pump for pumping down the tubing into the formation. It is important to prevent the reaction from starting until as late as possible in order to permit the HFG to be pumped through the tubulars and into the formation during the first hour of life, before it attains its Bingham plastic state.

A typical Cornell Unit, San Andres well contains five main pay members and is cased with 14.0 cm (5.5 inch) or 17.8 cm (7.0 inch) casing selectively perforated with about 20 holes varying from 1499.6 m (4920 feet) to 1578.9 m (5180 feet). Wellbore equipment for the treatment consists of 7.3 cm (2.875 inch) O.D. tubing and a full bore treating packer.

The normal matrix acid stimulation of a typical well consists of 28.4 m^3 (7500 gallons) of 15% non-emulsifying, iron stabilized HCl acid in five stages of 5.7 m^3 (1500 gallons) each and 11.4 m^3 (3000 gallons) of HFG in four stages of 2.8 m^3 (750 gallons) each. After injection is established into the formation, the first stage of acid is pumped into the tubing followed by a 4.0 m^3 (25 barrel) pad of fresh water, the first stage of HFG, another 4.0 m^3 (25 barrel) pad of fresh water and the first portion of the second stage of acid. When the volume of the second stage of acid equals the volume of the tubing plus the casing volume between the treating packer and the lowest perforation, all pumping is stopped for 30 minutes. This permits the HFG to fully complex within the formation and become a Bingham plastic fluid. Following the 30 minute shut-down, the remainder of the second stage of acid is pumped, followed by a 4.0 m^3 (25 barrel) fresh water pad, the second stage of HFG, another 4.0 m^3 (25 barrel) fresh water pad and the first portion of the third stage of acid. All pumping is stopped again for 30 minutes to permit the second stage HFG to fully complex within the formation. This same procedure is continued throughout the five stages of acid and four stages of HFG and the entire treatment takes approximately six hours. All wells to date have been swabbed for several days to recover the spent acid and HFG.

ACID STIMULATION USING OTHER TYPES OF DIVERTING METHODS

Four other methods have been employed on the Cornell Unit to divert acid during stimulation treatments. These include closely spaced straddle packers, Benzoic acid flakes, rock salt and ball sealers. Rock salt and ball sealers have been used so seldom that an evaluation of their effectiveness would be inconclusive. Therefore, only straddle packers and Benzoic acid flakes will be discussed here.

Closely Spaced Straddle Packers

Since the main porosity members of the San Andres formation have been selectively perforated with only about 20 holes over some 79.2 m (260 feet), it is usually possible to span each individual perforation with packers which are 1.8 m (6.0 feet) apart. A schematic of this straddle packer assembly (SPA) is shown in Figure 2. The packers are located above and below the bottom perforation through the use of the tubing tally and the mechanical casing collar locator. The slips on the lower packer permit it to stay in position as the tubing is lowered thereby driving the inner sleeve of the unloader downward the necessary 12.7 cm (5 inches) to open the unloader ports. Before the tubing is lowered further, such that the upper and lower packer elements begin to expand from the weight of the tubing, the tubing and casing are communicated at the unloader ports permitting circulation to take place. This allows the 15% non-emulsifying, iron stabilized HCl acid to be spotted between the packers at the perforations. The weight of the tubing is then permitted to be transferred to the packers. This fully expands the packer rubbers to form a seal above and below the perforation. Pressure between the packers merely acts to further set the slips of both the upper and lower packers. A matrix acid treatment using approximately 2.3 m^3 (600 gallons) of acid is then performed on that perforation. A surface pressure of 12.4 MPa (1800 psig) is not exceeded and the treating rate is kept at 2.4 m^3/h (.25 barrel per minute) at any surface treating pressure greater than 5.5 MPa (800 psig). A rate of 19.1 m^3/h (2 barrels per minute) is not exceeded, even if the pressure falls below 5.5 MPa (800 psig). During breakdown and treating the casing-tubing annulus is left open to check for communication with other perforations up the hole. If communication is detected, the casing-tubing annulus valve is closed and the treatment continues. After the bottom perforation is treated the SPA is moved up the hole to span the next higher perforation, the packers are set and the perforation is treated in the same manner. This procedure is repeated until all the perforations are treated. Typically about 80% of the perforations treated in this manner communicate.

Benzoic Acid Flakes

This method of diverting acid during a stimulation treatment is very similar to the HFG method. The only difference is that instead of HFG there are four equal stages of a gelled fluid carrying 90.7 to 136.1 kg (200 to 300 pounds) of Benzoic acid flakes and no 30 minute shut-down is necessary.

The principle of diversion by Benzoic acid flakes is their graded sizes form a filter cake on the formation at the perforation.[2] They are soluable in both oil and water so they should not permanently plug the perforation.

RESULTS

There are a number of ways that the results of acid stimulation treatments can be evaluated. Producing wells are commonly examined using techniques such as "spinner" surveys and production tests after production begins. Water injection wells are frequently evaluated by radioactive injection profiles, "spinner" surveys and overall rates after water injection begins. Both of these classes of wells can be evaluated during acid stimulation through the use of temperature surveys and radioactive "tagging" of the treating materials followed by logging.

After producing wells are put on production, "spinner" surveys are difficult and expensive to run. Since all Cornell Unit wells are put on beam pump, a dual wellhead must be used and the bottom-hole pump must be set above all the perforations without the benefit of a tubing anchor. Following the survey, the rods and tubing must be pulled so a tubing anchor can be installed and the pump lowered as much as possible. Because of the considerable expense involved in this procedure, very few of these surveys have been conducted on the Cornell Unit.

Production tests have proven unreliable as a means of evaluation because it is difficult to determine the effect of differences in reservoir quality between wells as well as which pay interval is producing what fluid.

Cornell Unit injection wells are conveniently evaluated by means of radioactive injection profile surveys. These are conducted on a routine basis and are far less expensive than "spinner" surveys. Overall injection rates are not a reliable means of evaluation because there is no indication of water distribution.

Temperature surveys are the only in-progress evaluation tool used during acid stimulation on the Cornell Unit. They have proven reliable and less expensive than other methods in evaluating treatments using HFG as a diverting agent. After a base temperature survey is run, additional surveys are conducted following each stage of acid to determine where the acid went.

Because of the difficulties and expense of the various evaluation techniques cited above, results of acid stimulation on the Cornell Unit using HFG, straddle packers and Benzoic acid flakes as diverting agents can be presented best by closely examining radioactive injection profiles and temperature surveys.

Porosity x Height Product (Øh) vs. Volume Plot

As mentioned earlier, a reconditioning and infill drilling program is in progress on the Cornell Unit. All injection wells now have casing solidly cemented through the productive interval with pay zones selectively perforated. As existing open hole production wells are converted to injection they too will be cased, selectively perforated and acid treated. All of this is being conducted to improve the overall waterflood and proposed tertiary recovery sweep efficiency.

It is generally recognized that injected water should be distributed in accord with each production zone's porosity x height product (Øh).[3] Therefore, a convenient way to evaluate the effectiveness of acid stimulation using various diverting agents is to determine the percent of water volume injected into each zone from radioactive injection profiles and comparing that to the Øh distribution. Figures 3, 4 and 5 graphically present the results of such a study.

Of the three diverting agents studied, it can be seen that the HFG offers the best Øh conformance. It should be pointed out that summarizing the data in this manner has a "masking"effect on individual well performance. For instance, in pay intervals where one well is severely under injecting, another, treated in the same manner, might be over injecting in the same proportion,so the sum of the two wells indicates perfect conformance. In spite of this difficulty, Figures 3, 4 and 5 reasonably represent what individual well conformance indicates, except that the overall conformance of straddle packers and Benzoic acid flakes is exaggerated optimistically.

Temperature Surveys

Figure 6 is an illustration of the type of acid distribution experienced on the Cornell Unit as indicated by temperature surveys conducted after each stage of acid during an HFG job. It can be seen that the HFG successfully diverted the acid within this injection well so that all 16 perforations were treated during at least one of the five stages.

FUTURE ACID STIMULATIONS USING HIGH FRICTION GEL

At the present time all HFG jobs are preceeded by an acid breakdown of each individual perforation using straddle packers. It is felt that this procedure assures that there is a hole in the casing and establishes communication with the formation.

In injection wells, which contain fiberglass casing, an SPA similar to that shown in Figure 2 is used except the packers are cup type without slips, there is a perforated nipple between the packers, and the unloader is above the top packer. After each perforation is broken down, this assembly is removed and a conventional treating packer is run in the hole open-ended and set in the steel casing just above the steel/fiberglass crossover point. The HFG job is then conducted.

In the producing wells, which contain steel casing, a different SPA is used which permits the assembly to remain in the hole and act as the treating packer during the HFG job. This assembly is identical to that shown in Figure 2 except a ported shear sub has been added between the bull plug and the bottom packer. At the completion of the straddle packer portion of the job, the assembly is pulled up above all the perforations, set and tested. Then a sinker bar assembly is run into the tubing on a sand line. When the sinker bar assembly sets down on the shear sub, a pin is sheared and a sleeve is driven down which opens the tubing to the casing below the packers.

Although a number of Cornell Unit wells have received this "combination" treatment, most of them have been producing wells which make evaluation difficult. One injection well treated in this manner has had a radioactive injection profile conducted and a Øh plot prepared. The results on this well appear very favorable but drawing any conclusions from an evaluation of one well would not be advisable.

CONCLUSIONS

1. Cornell Unit injection wells which have received acid treatments using HFG as a diverting agent have displayed better vertical sweep efficiency (Øh conformance) than wells where other diverting methods were used.

2. Temperature logs run during HFG jobs indicate that it can successfully divert acid so all pay intervals are treated.

3. Further evaluation should be conducted of acid treatments using combination SPA/HFG diverting methods.

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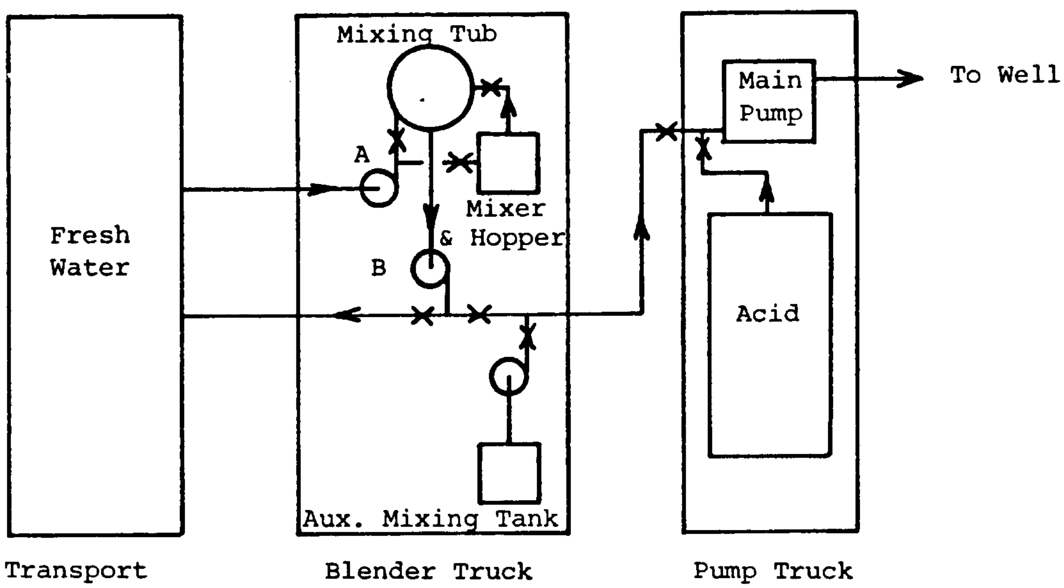

FIGURE 1—MIXING AND PUMPING EQUIPMENT LAYOUT

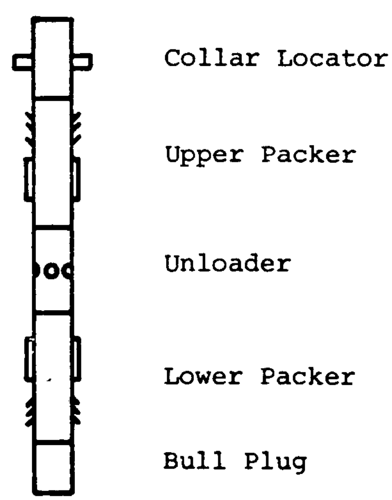

FIGURE 2—STRADDLE PACKER ASSEMBLY

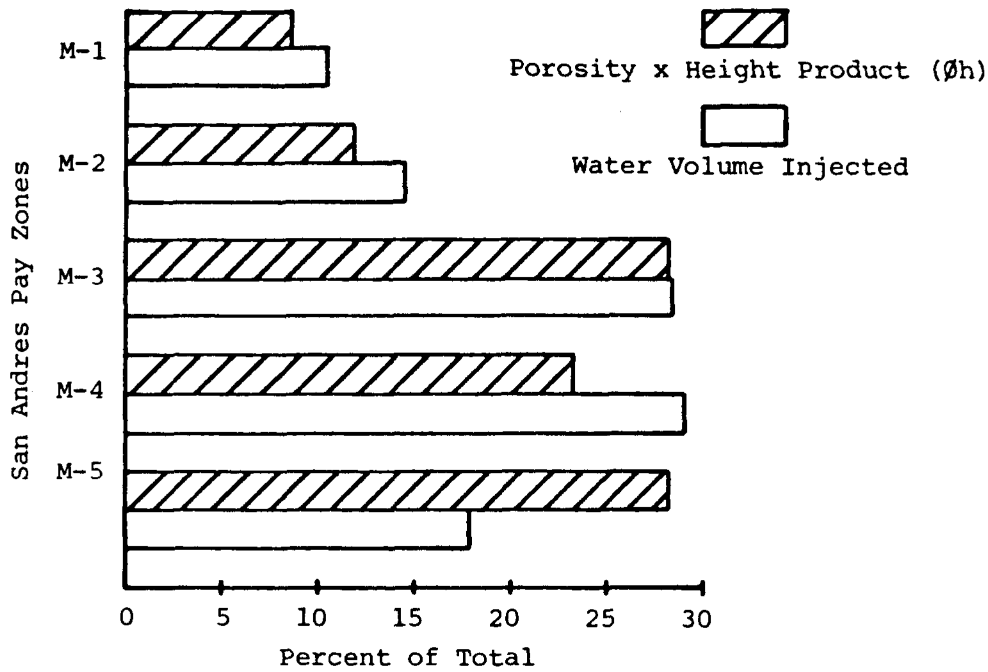

FIGURE 3—WATER INJECTION CONFORMANCE TO Øh DISTRIBUTION FOR WELLS WHICH USED HIGH FRICTION GEL FOR ACID DIVERSION.

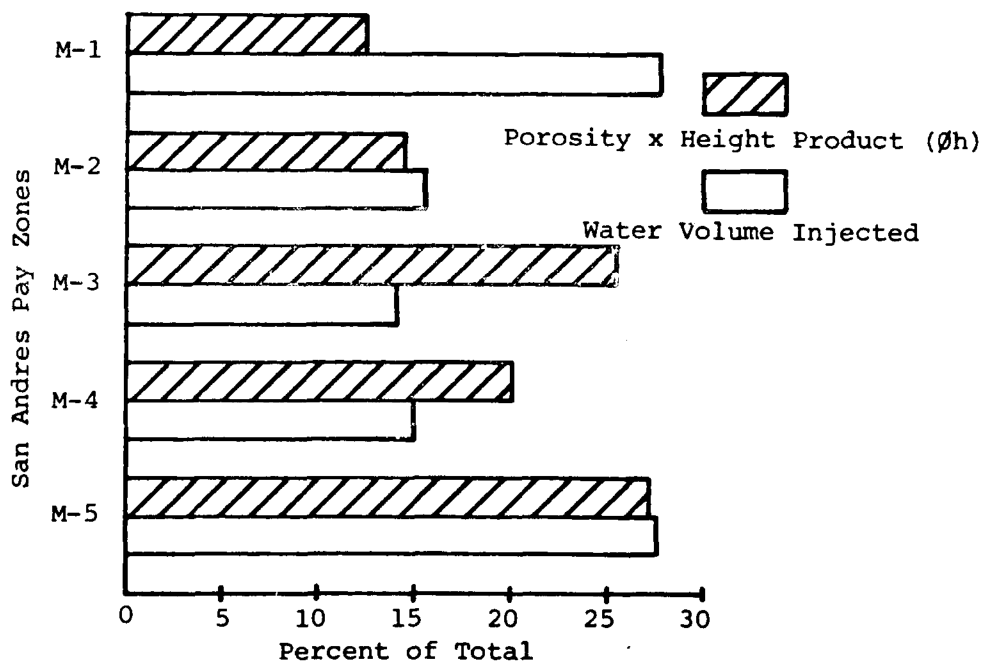

FIGURE 4—WATER INJECTION CONFORMANCE TO Øh DISTRIBUTION FOR WELLS WHICH USED STRADDLE PACKERS FOR ACID DIVERSION.

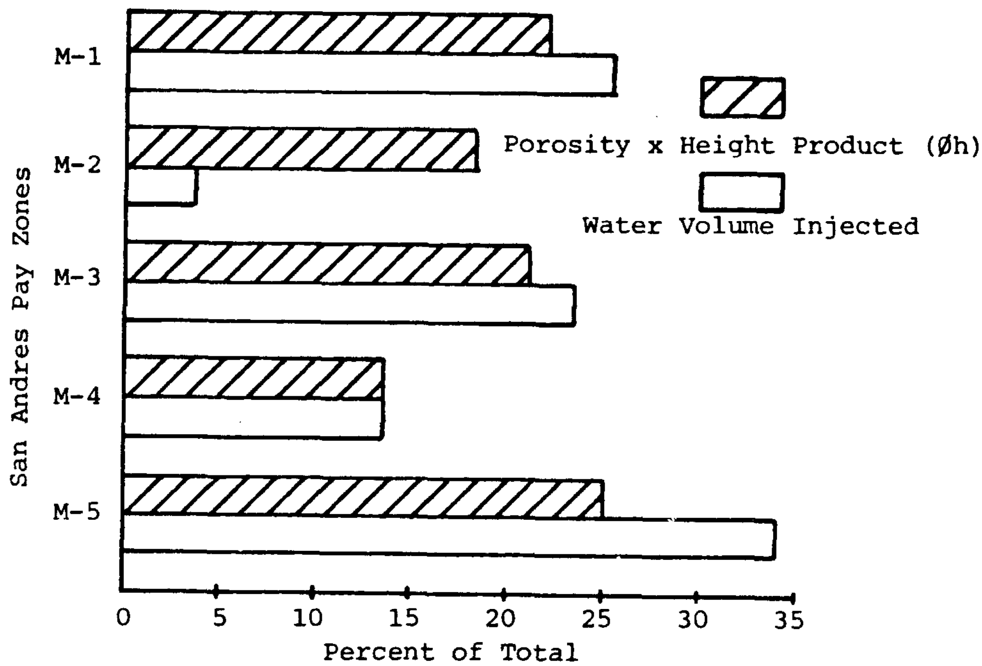

FIGURE 5—WATER INJECTION CONFORMANCE TO Øh DISTRIBUTION FOR WELLS WHICH USED BENZOIC ACID FLAKES FOR ACID DIVERSION.

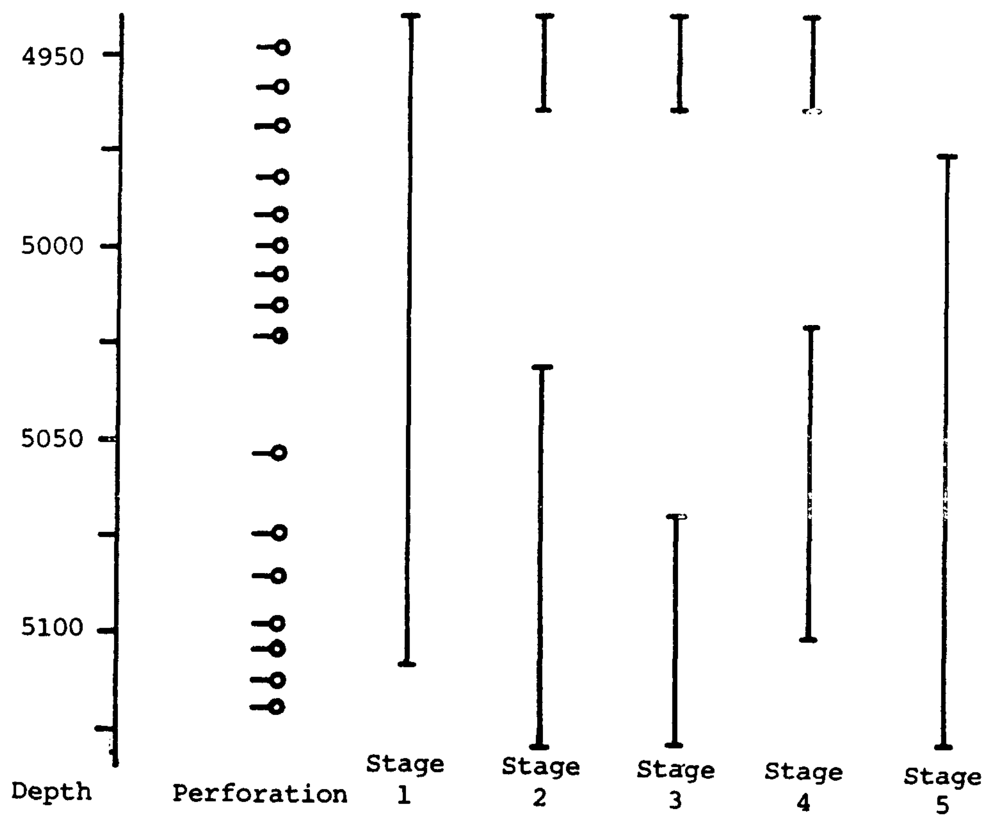

FIGURE 6—TYPICAL ACID DISTRIBUTION FOUND BY TEMPERATURE SURVEYS DURING TREATMENT WHICH USED HIGH FRICTION GEL FOR DIVERSION.