AN ULTRADEEP APPLICATION FOR STABLE FOAM DRILLING

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ABSTRACT

In recent years, the use of foam has proven to be successful in drilling underpressured formations where conventional drilling fluids have been unsatisfactory. On the E. O. Reed Well No. 1-A, foam was successfully used by Getty to drill and complete an underpressured formation at a depth of over 22,000 ft.

This presentation includes a discussion on the background of the E. O. Reed 1-A and how foam was selected as a drilling fluid. Also discussed are foam characteristics, foam components, planning and design considerations, foam drilling operations, results of the well completion and conclusions of this study.

BACKGROUND

The E. O. Reed 1-A is located in the Gomez Field, 12 miles northwest of Fort Stockton, in Pecos County, Texas (Fig. 1). It was drilled as a replacement well to the E. O. Reed No. 1, which developed downhole problems and had to be abandoned after producing approximately 40 BCF of gas from the Ellenburger Formation. Prior to abandonment, the well produced at a rate of 7 MMCF of gas per day with 800 psig tubing pressure on a 1 in. choke. The Ellenburger formation in this area is a dolomite encountered at approximately 22,000 ft. and characterized by porosity ranges within the pay interval of 3 to 8 per cent. Production is predominantly attributed to fracture permeability. The advanced stage of depletion in this gas reservoir is reflected by a decrease in reservoir pressure from approximately 9250 psig to the current estimated pressure of 2700 psig. In order to drill through this zone in balanced conditions of pressure, a mud weight of less than 3.0 lb/gal would be required.

Getty's conventional drilling program for an Ellenburger completion in this area is as follows (illustrated on Figure 2):

- -a 26 in. hole drilled with fresh water to 900 ft. and 20 inch O.D. casing set;

- -a 17-1/2 in. hole drilled with fresh water to 4900 ft. and 13-3/8 inch O.D. casing set;

- -a 12-1/4 in. hole drilled with cut brine to 10,800 ft. and 9-5/8 inch O.D. casing set;

- -an 8-1/2 in. hole drilled with oil base or benex mud to 17,750 ft. and a 7-3/4 inch O.D. liner set; and

- -a 6-1/2 in. hole drilled with cut brine to TD and a 5-1/2 inch liner set.

A number of conventional Ellenburger completions have been attempted in the Gomez Field in the last five years. The last documented success was completed in early 1978. The unsuccessful attempts may be attributed to excessive amounts of drilling fluid lost in the Ellenburger, resulting in a decrease in potential productivity of the well. In preparation for drilling the Reed I-A an alternative method for drilling this interval had to be developed.

Figure 3 compares densities of commonly used drilling fluids. As noted previously, the Ellenburger formation pressure in the Reed I-A is equivalent to less than 3.0 lb/gal mud weight. Due to the low fluid density required to prevent lost circulation, alternative fluids studied for drilling the Ellenburger section included:

1) Air or mist,

2) Natural gas or nitrogen, and

3) Foam.

Air or mist was eliminated from consideration due to the potential for downhole explosions and excessive corrosion at the depths and temperatures to be encountered. Natural gas or nitrogen was eliminated due to the large volumes required to perform the job and the possible dangers involved in handling the gases on the surface. Based on this and other considerations discussed in the next section, foam was ultimately selected as the fluid to be used in drilling and completing the Ellenburger interval on the replacement well.

FOAM CHARACTERISTICS

The basic components of stable foam consist of water (brine, KCl or fresh), a foaming agent, and gas (air, natural gas or nitrogen). The components are combined on the surface to form a homogenous foam which is pumped into the drilling rig's circulating system. Liquid is the continuous phase of the foam and gas the discontinuous phase. For the foam to maintain its homogenous quality, the proportion of liquid to gas (liquid-volume fraction) must be kept within specific limits--generally between 2 per cent and 16 per cent on the surface. Good, stable foam is the consistency of shaving lather and exhibits excellent solids carrying capabilities. If the foam becomes too wet, however, it behaves like wet shaving lather, losing viscosity and the ability to support its own weight and the solids entrained in it. A foam with too low of a liquid-volume fraction will exhibit behavior similar to that of wet foam. Air pockets become entrapped in the foam as shown on Figure 4. The foam itself retains its lifting ability, but the air pockets have a lifting or carrying capacity much less than that of foam, and thus reduce net solids carrying capability.

A good quality foam requires much less annular velocity to carry cuttings out of the hole than does liquid, air or gas.

Generally, foam requires one-half the velocity for proper hole cleaning as does liquid and up to a tenth of the velocity required for drilling with air or gas.

Unlike liquid, foam is a compressible material and, thus, changes properties with changes in temperature and pressure. If foam is to be effectively used as a drilling fluid, it must remain in a foam state from point of entry into the wellbore, around the bit, and back out the discharge. If at any point in the system the foam changes to a mist or liquid, solids carrying capacity of the fluid is greatly reduced.

FOAM COMPONENTS

Foam drilling in underpressured sections is successful if the following conditions exist:

1) The wellbore is contacted only by a noncontaminating, non corrosive, stable foam.

2) The foam's stability results in maximum solids carrying capacity, and

3) The hydrostatic head of the foam column is no greater than the formation pressure so that liquid or solid particles do not invade the potentially productive zone.

The static bottom hole temperature anticipated in the E. O. Reed 1-A was approximately 350° F. Despite laboratory data, the stability of foam used at this temperature was uncertain. In order to meet the above conditions, the goal in selection of specific foam components was to eliminate as many sources of corrosion and instability as possible. The foam ultimately selected for drilling the Reed 1-A consisted of the following components:

1) Nitrogen gas--chosen over air or natural gas because it eliminated the possibility of a downhole explosion and is not corrosive.

2) High temperature foaming agent--lab tested for stability at 400° F for six hours.

3) Corrosion inhibitor--used for tubular protection.

4) Oxygen scavenger--used to eliminate free oxygen from the system, and

5) Fresh water--treated with caustic soda to maintain a pH of 9.5 to 10.0.

The components were combined and tested in the lab for compatibility prior to actual operations. Fresh water sources in the area were tested to determine which would provide the lowest solids content and thus eliminate as many possible sources of contamination to the foam as possible. This precaution, in addition to nitrogen and high temperature foaming agents, should be taken at temperatures greater than 240° F and depths over 13,000 ft. to insure foam stability.

PLANNING AND DESIGN CONSIDERATIONS

Drilling an underpressured reservoir with foam required some modification to the conventional drilling practices used in this area. Drilling below the 7-3/4 in. liner (17,750 ft. and deeper) requires mud weights up to 9 lb/gal to contain some intervals. If the Ellenburger porosity were drilled with this weight fluid, lost circulation would certainly occur. To rectify this, the 6-1/2 in. hole was drilled with cut brine to the top of the Ellenburger porosity at 22,244 ft. where a 5-1/2 in. liner was set. From that point, a 4-1/2 in. hole would be drilled with foam and a 3-1/2 in. slotted liner run to total depth at 22,650 ft. This would isolate the zones of differing formation pressure and eliminate the potential of a kick from the upper interval and lost circulation in the Ellenburger. This modification is illustrated on Figure 5.

A related problem resulted from the extremely low hydrostatic pressure exerted by a column of foam. A number of wells in the Gomez Field had been lost due to collapse of the 7-3/4 in. liner while working at depths below it. The interval behind the 7-3/4 in. liner (from 10,700 ft. to 17,750 ft.) is overpressured and can require mud weights up to 15.5 lb/gal to drill through safely. Maximum mud weight on the Reed 1-A through this interval was 13.5 lb/gal. With high pressure behind and foam inside the 7-3/4 in. liner, collapse limitations were approached. To eliminate the potential for collapsed casing, pore pressure of the interval from 10,700 ft. to 17,750 ft. was plotted and studied. Areas of highest pore pressure (those zones where the potential for collapsed pipe was greatest) were identified and the 5-1/2 in. liner top was located to cover these zones. The overlap of the 5-1/2 in. pipe into the 7-3/4 in. pipe was extended from the normal 400 ft. to 2772 ft. to serve as additional support for the 7-3/4 in. liner over the highest pressured zones. The 5-1/2 in. liner was then run from 22,244 ft. to 15,014 ft. and cemented in one stage (Fig. 5).

Drilling a 4-1/2 in. hole with foam below 22,000 ft. created concern about drill string stability. A parted drill string at 22,000 ft. could have resulted in many days spent on fishing operations. The goal in designing the drill string was to provide for the sturdiest string possible, yet provide enough clearance to fish the string if necessary. A slick bottom hole assembly was used to eliminate excessive torque problems. Fifteen 3-1/2 in. x 1-1/2 in. drill collars with 2-3/8 in. IF connections were used with 2-7/8 in. Grade "E" AOH 10.4 lb/ft drill pipe run in the 5-1/2 in. liner. Approximately 4900 ft. of 3-1/2 in. Grade "E" IF 15.5 lb/ft, 4950 ft. of 4-1/2 in. Grade "E" XH 20 lb/ft and 5150 ft. of 4-1/2 in. Grade "G" FH 20 lb/ft drill pipe made up the remainder of the string from bottom to top. This design is illustrated on Figure 6.

Selection of bits was made based on availability, cutting size, and bit life considerations. Both journal-bearing bits and diamond bits had been used successfully in previous foam drilling applications. The availability of 4-1/2 in. journal-bearing bits for medium-hard formations was limited, however, while diamond bits were readily available. Cuttings from a journal-bearing bit are much larger than that of a diamond bit. Since smaller cuttings are much easier for the foam to carry out of the hole, hole cleaning should be maximized with the use of diamond bits. Finally, a relatively short bit life was anticipated from a journal-bearing bit due to the small bearing size in a 4-1/2 in. bit. On the other hand, one or two diamond bits were expected to drill the entire 406 ft. Ellenburger section. Based on these three factors, diamond bits were selected for use on the E. O. Reed No. 1-A. Once diamond bits were selected, the desired total flow area (TFA) through the bit had to be determined. The TFA is a function of the flow area built into the bit due to diamond exposure (distance from bit matrix surface to the diamond tip), and the flow area built into the bit's fluid course areas. Ordinarily, fluid velocity is maximized by increasing the pressure drop across a diamond bit for cooling and cleaning purposes. In this situation, however, it was felt that pressure drop should be minimized to maintain stability of the foam. For this reason, the TFA built into the first diamond bit used was 0.6 sq. in.--the maximum flow area that could be built into that bit.

FOAM DRILLING OPERATIONS

Few surface equipment modifications were required to drill the Ellenburger interval with foam. A tee was installed on the discharge side of the mud pumps to allow the foam to be pumped into the rig's normal circulating system. An 8 in. discharge line was installed below the rotating head, bypassing the shale shaker out to the reserve pit. A bladder type back pressure valve was installed on the line to control annular back pressure on the system. The back pressure was monitored and controlled remotely from the foam units. An air compressor was installed on a lateral to the discharge line. In the event that gas reached the surface while tripping, the compressor could be used to create a vacuum and divert gas from the rig floor to the flare line.

A schematic of foaming operations is shown on Figure 7. The water was treated in the rig's steel pits with caustic soda to maintain a pH of 9.5 to 10.0 and oxygen scavenger was added at a rate of 6 qts/100 bbl. The water was then pumped to the two foam units' 40-barrel storage tanks where corrosion inhibitor and foaming agent were added at rates of 2 qts/tank and 16 gals/tank, respectively. From there the treated water was pumped by the unit's triplex pump (maximum rating 92 gal/min at 1000 psi) into the foam generator. Here the water was mixed with the nitrogen to create a homogenous, stable foam. The foam was then pumped into the rig's circulating system. It was pumped down the drill pipe, around the bit, up the annulus, and out to the reserve pit via the discharge line. The foam makes one pass only--it is not recirculated as are other drilling fluids. A 24 hour supply of fresh water and nitrogen was stored on location at all times to eliminate the possibility of a shutdown due to reductions in deliveries.

A computer program furnished by Foamair assisted in completing this foam drilling project. The program utilizes casing and drill string design, gas and water injection rates, annular back pressure, surface temperature, and geothermal gradient as input data. Circulating pressure, liquid-volume fraction, friction pressure, temperature, and annular velocity are calculated in 1000 ft. increments of the wellbore. A series of graphs are then developed such as those shown on Figure 8. These graphs are used as field references in the event that adjustments are needed. Generally, increasing the gas rate will reduce circulation pressure at the bit and increase lifting capacity of the foam. An increase in liquid rate will reduce injection pressure or increase circulation pressure at the bit. Annular back pressure is primarily used to control circulation pressure at the bit to avoid a high liquid-volume fraction. Increasing annular back pressure will result in an increase in injection and circulation pressure at the bit.

Based on the anticipated formation pressure on the Reed I-A, the circulating pressure at the bit was to be held at 3000 to 3500 psig. To generate this pressure, 1000 SCF/min of nitrogen and 30 to 40 gal/min of water were pumped while maintaining an annular back pressure of 40 to 60 psig. Injection pressure varied from 450 to 600 psig at the foam units.

To trip out of the hole, a measured volume of treated fresh water was pumped to sufficiently overcome the formation pressure. In this manner, tripping operations could be carried out without the risk of gas to surface.

To unload the hole between trips, up to 70 gal/min of water and 1000 scf/min of nitrogen were pumped to establish circulation. Heavier foam was used to lift static water out of the wellbore since a lighter foam would tend to percolate up through the water and not carry it out of the hole. Once circulation occurred, the water content of the foam was gradually reduced to the point desired for drilling. When a consistent foam circulated to the surface, drilling resumed.

A string float valve was installed immediately below the kelly. When making a connection, prior to breaking the kelly, nitrogen was shut off and treated water was pumped into the circulating system past the string float valve. When the kelly was broken out, foam and pressure were contained in the drill string. During this process, foam continued to flow up the annulus and out the discharge line due to expansion. Once the connection was made and drilling resumed, circulation was normalized.

Gas or water influx, if encountered in excessive volumes, can be detrimental to the stability of foam. Quantities of gas or water influx that can be tolerated by the foam system are dependent upon downhole conditions (i.e., depth, temperature, pressure). To insure that levels of influx are tolerable, the quality of the foam is monitored as it leaves the discharge line. If while drilling, the foam is of good quality, flows in a continuous column with no surging, and carries cuttings out of the hole, there is little need for concern. If the foam appears wet, flows in slugs or surges, and few cuttings are detected, then drilling must cease and the problem rectified before continuing. In most cases, a change in the liquid-volume factor or the back pressure held on the annulus will correct the problem and drilling operations may resume. The original Reed well produced less than 50 barrels of water per day --not enough to substantially affect the foam's stability. Of greater concern was the fact that gas had entered into the wellbore through the 7-3/4 in. liner top while drilling the 6-1/2 in. hole on the Reed I-A. As a precaution, a negative test was run on the liner top prior to displacing the hole with foam. The results indicated that this gas had depleted and would have no effect on the foam.

Maintaining a tolerable corrosion rate on the Reed I-A was essential because of the extreme temperatures the drill string would encounter at 22,000 ft. and below. Corrosion rate of the foam was monitored using probes installed in the inlet and discharge lines. Corrosion rates were checked every six hours with a corrator and maintained at 4 mpy or less. In addition, a corrosion coupon was placed in the drill string at the surface and checked each trip out of the hole.

RESULTS AND POTENTIAL

The 406 ft. Ellenburger section was drilled successfully with the foam system. All elements performed as expected with the exception of the diamond bits. Of the 11 days required to drill the interval, 5.6 (134-1/4 hours) were spent drilling, while the remaining 5.4 days (129-3/4 hours) were spent tripping and circulating for new bits. Five diamond bits were required to complete the hole with performance per bit averaging 81.2 ft. and 26.9 hours. The bits appeared to be overheated, indicating insufficient cooling by the foam. The TFA of one bit was changed from 0.6 sq. in. to 0.25 sq. in. to increase fluid velocity and enhance cooling, but no significant change in performance was noted. Additional research is needed to study the effect of foam generated hydraulics on bit performance.

The drill string design proved sufficient to withstand the five round trips for new bits. Corrosion on the string was minimal. The foam, in general, was of good quality, carried cuttings out of the hole adequately, and performed its function of eliminating lost circulation. For best results, the liquid volume fraction of the foam was maintained between 13 and 16 per cent. Foam with liquid-volume fractions below 13 per cent appeared wet, surged out the discharge line and did not carry cuttings out of the hole adequately. From this experience it was found that the liquid-volume fraction required to maintain a good quality foam at 22,000 ft. differs greatly from that required at shallower depths.

One month after completion, the well was producing 4.0 MMCFPD gas and 118 bbl/day of water with 850 psig tubing pressure on an 18/64 in. choke. The well is now restricted to 50 per cent deliverability due to gas purchaser curtailment. Water production has declined to approximately 25 bbl/day.

One key to the success of the E. O. Reed No. 1-A was proper planning. Drilling with foam requires many more man hours in preparation than does conventional drilling. Meetings were held well in advance of actual foaming operations, allowing time to anticipate and discuss potential problems. The additional information personnel gain from this preparation pays off in every aspect of drilling operations. Another key to the success of this project, as well as any other project, was the genuine commitment of all parties involved. This commitment is vital when utilizing new techniques or applying proven techniques to more hostile conditions.

The potential for stable foam as a drilling and workover fluid is considerable. It has proven itself to be reliable and effective at depths up to 23,000 ft. and temperatures to 350° F. The foam system does have its drawbacks--not the least of which is the time and expense required. The benefits derived on the E. O. Reed No.

1-A, however, far surpassed these drawbacks. Many wells similar to the Reed 1-A, previously considered unfeasible to drill or work over, can now be successfully completed with a stable foam system. As experience and research are developed, foam will be more and more instrumental in the completion of these wells.

CONCLUSIONS

1) Foam can be successfully used as a drilling and workover fluid to depths up to 23,000 ft. where effective mud densities range from 0.3 lb/gal to 7.0 lb/gal and water or gas influx are moderate.

2) Proper planning is a critical element in the successful completion of foam drilling operations.

3) Nitrogen and high temperature foaming agents are required for foam generation when the temperature encountered in the wellbore exceeds 240° F or the depth to be drilled exceeds 13,000 ft.

4) Additional research is needed to study the effect of foam generated hydraulics on bit performance.

REFERENCES

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2) Millhone, R. S.; Haskin, C. A.; and Beyer, A. H.: "Factors Affecting Foam Circulation in Oil Wells" SPE paper No. 4001.

3) Beyer, A. H.; Millhone, R. S.; Foote, R. W.: "Flow Behavior of Foam As A Well Circulating Fluid", SPE paper No. 3986.

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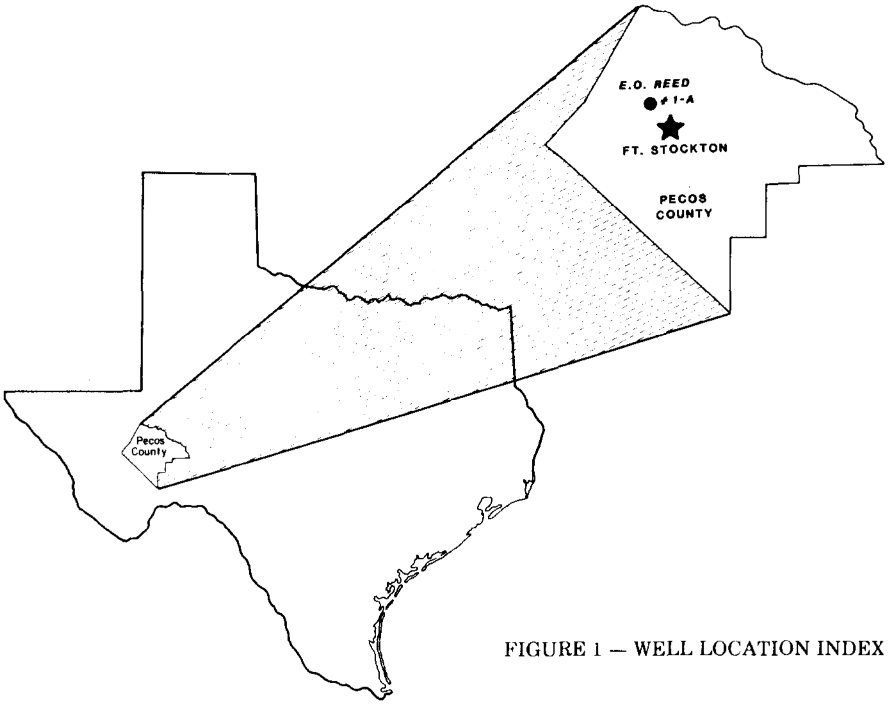

FIGURE 1 — WELL LOCATION INDEX

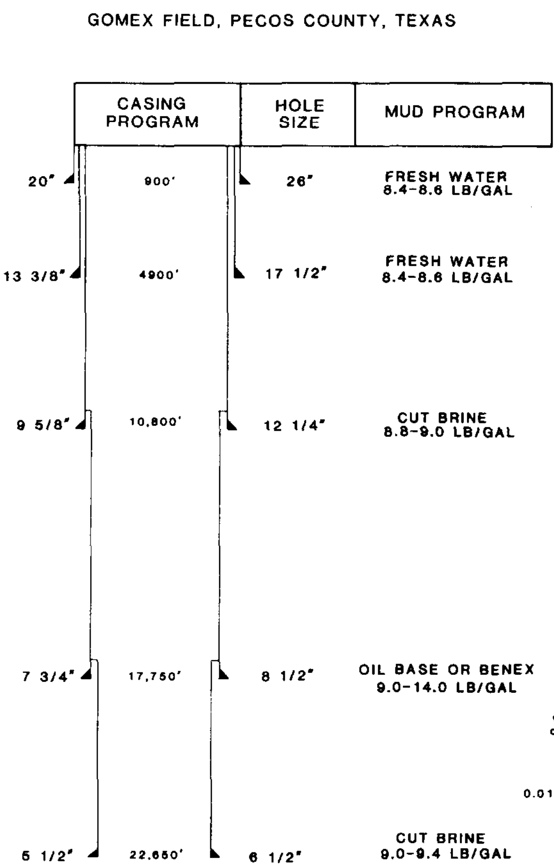

FIGURE 2 — CONVENTIONAL DRILLING PROGRAM

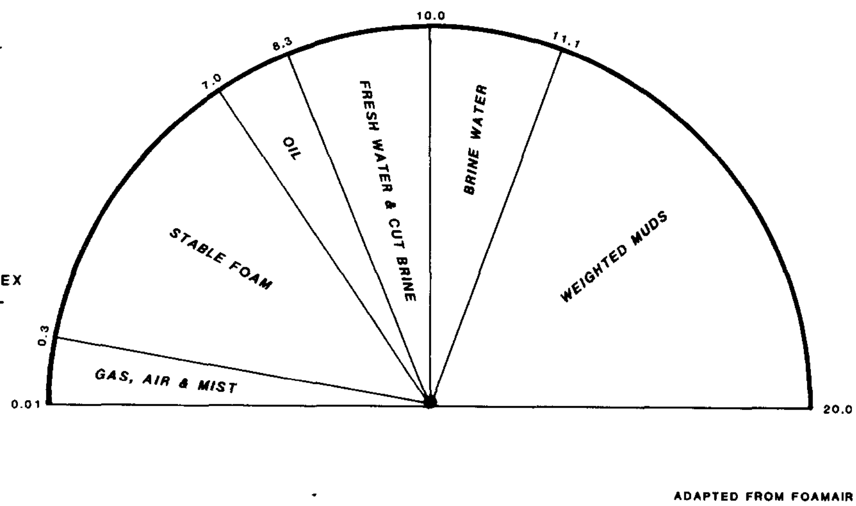

FIGURE 3 — DRILLING FLUID DENSITY (LB/GAL)

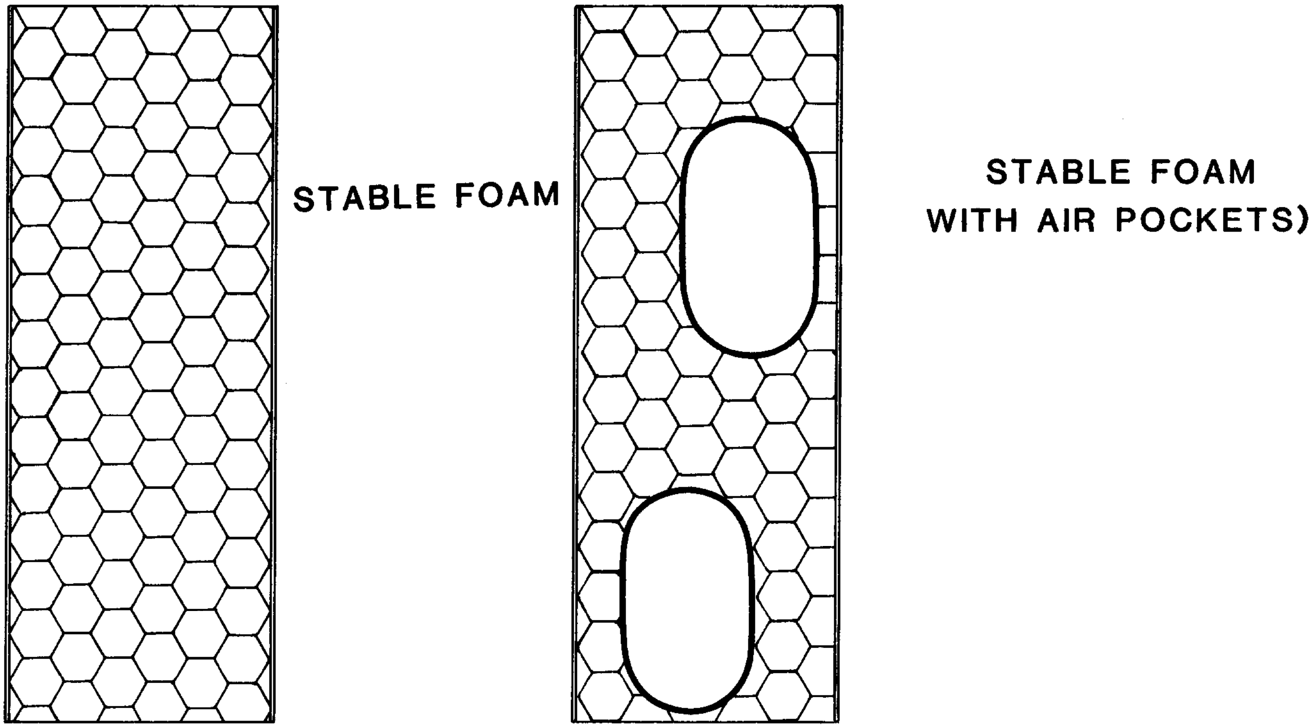

FIGURE 4 — FLOW REGIMES

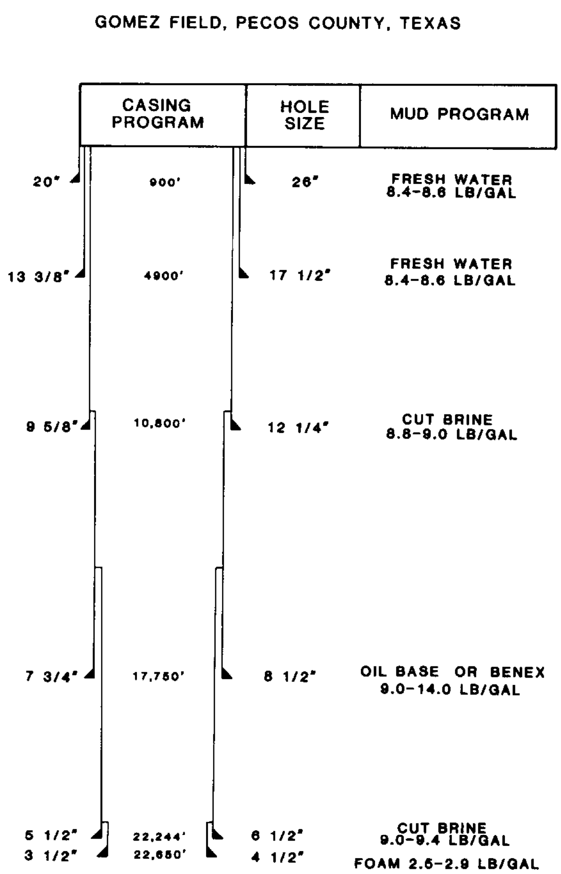

FIGURE 5 — MODIFICATION OF CONVENTIONAL DRILLING PROGRAM **FOR FOAM DRILLING**

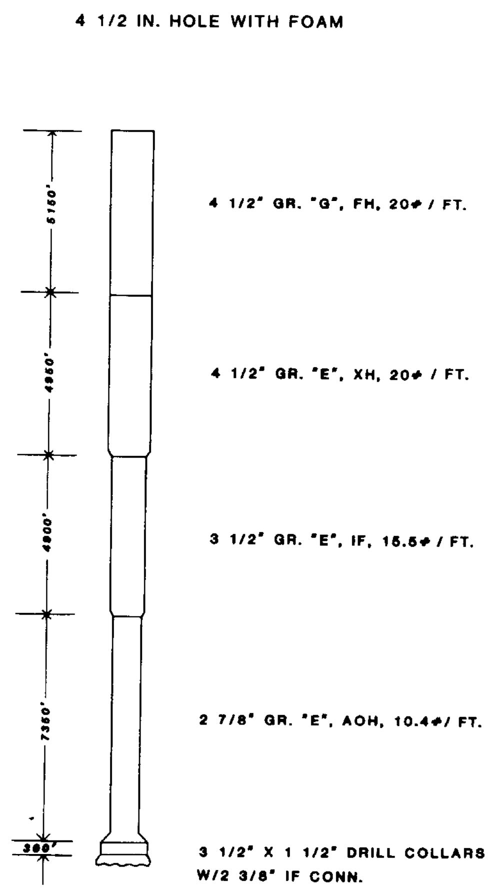

FIGURE 6 — DRILL STRING DESIGN FOR DRILLING

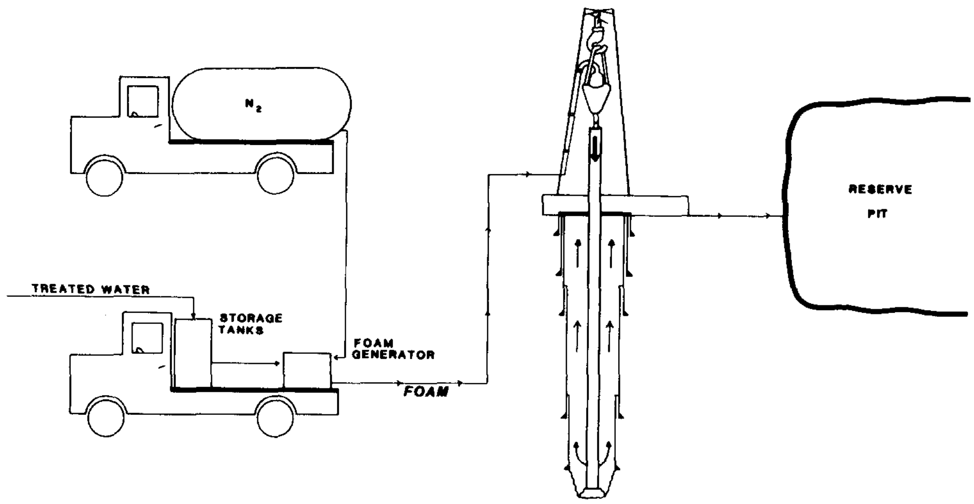

FIGURE 7 — FOAM OPERATIONS SCHEMATIC

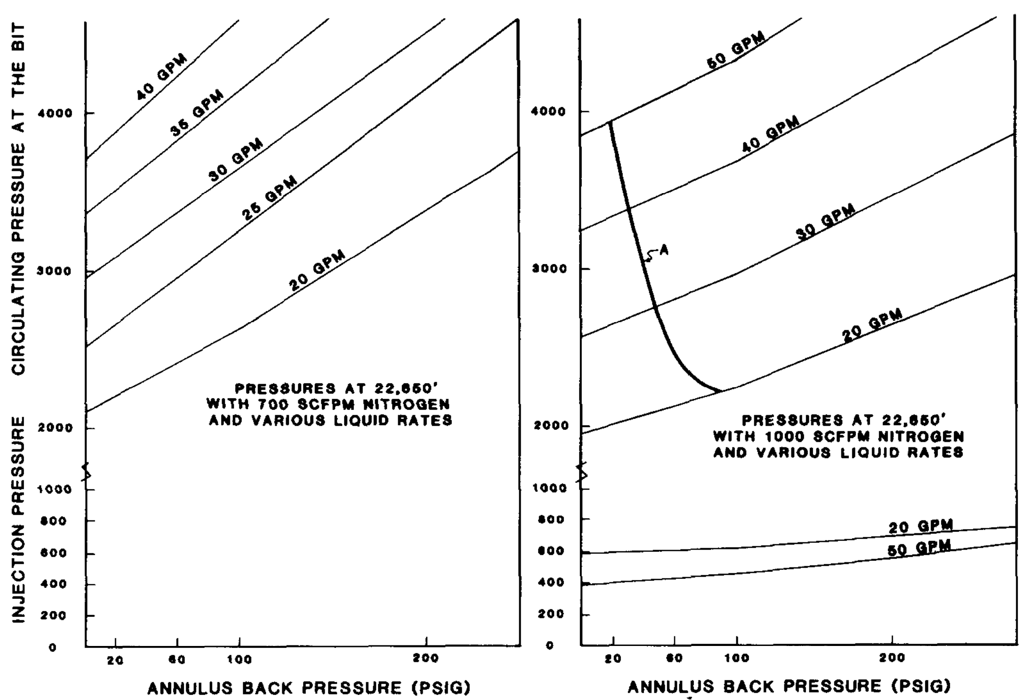

FIGURE 8 — ANNULUS BACK PRESSURE (PSIG) & ANNULUS BACK PRESSURE (PSIG)