COMPLETION AND STIMULATION PROGRAMS IN THE SPRABERRY TREND OF WEST TEXAS

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INTRODUCTION

Increased demand for crude oil and the higher prices being paid for petroleum products have caused a resurgence of activity in the Spraberry Trend of West Texas, (Fig. 1). Even though it is one of the largest producing areas in the industry it has always been somewhat of an enigma to those working with it. However, with proper planning and execution of the completion phase, new wells in the Spraberry-Dean sections, and re-completions in the Dean zone can be economically attractive.

The Spraberry and Dean zones are primarily siltstones with very low matrix permeability and porosity. Extensive natural fractures occur throughout the zones. It is the existence of these fractures that provides enough fluid movement and fluid storage to make completion from the zones economically feasible. Due to the nature of these formations, they require a successful hydraulic fracture treatment to provide the needed productivity. Two very influential factors to be considered in planning the stimulation treatment are: zone separation and fluid selection.

In order to properly stimulate each zone, it is necessary to keep them separate during the stimulation process. The existence of natural fractures favors extension of the induced fractures beyond the vertical limits of the perforated intervals. In addition, there is a significant difference in the fracturing pressures of the zones, thereby creating a pressure differential across any unperforated interval. It is general practice to maximize the length of this unperforated zone of separation. One popular method for staging the subsequent stimulation treatment is the "ring and bomb" procedure; another is to take advantage of this natural pressure difference between the Dean and Lower Spraberry zones to effect sequential stimulation without benefit of mechanical separation.

When stimulating formations with low permeabilities it is necessary to create deeply penetrating fractures in order to obtain adequate drainage. In the case of the specific formations under consideration, large induced fracture heights occur regularly. The end result is the creation of very large fracture areas requiring large quantities of frac fluids. Therefore, it is very important that the fluid chosen provides a balance of fluid efficiency, cost, and clean-up characteristics.

Production data on a well-to-well basis is erratic; however, studies of selected groups of wells lead to the general conclusion that bigger frac jobs provide for more ultimate oil recovery. This return on investment is an exponential function and experimentation is still being conducted in an attempt to better define the optimum limits. In addition to fracture penetration, the sand program used and the fracture widths created seem to also have an effect on the production history.

HISTORY

The Spraberry Trend was the scene of the last big drilling "boom" in West Texas. This drilling activity reached a feverish pitch about 25 years ago in the early 1950's. At that time over 250 rigs were active in the Trend. With a wave of nostalgia one recalls — caliche dust hovering over the entire countryside and so deep in places it hid enormous "chuck" holes that could wreck a vehicle — a shortage of personnel so severe that rig crews drove from rig to rig and received full tour pay for making a trip — the meeting place of the oil people being dubbed Hadacol Corner after a popular patent medicine of the time — the birth of a new

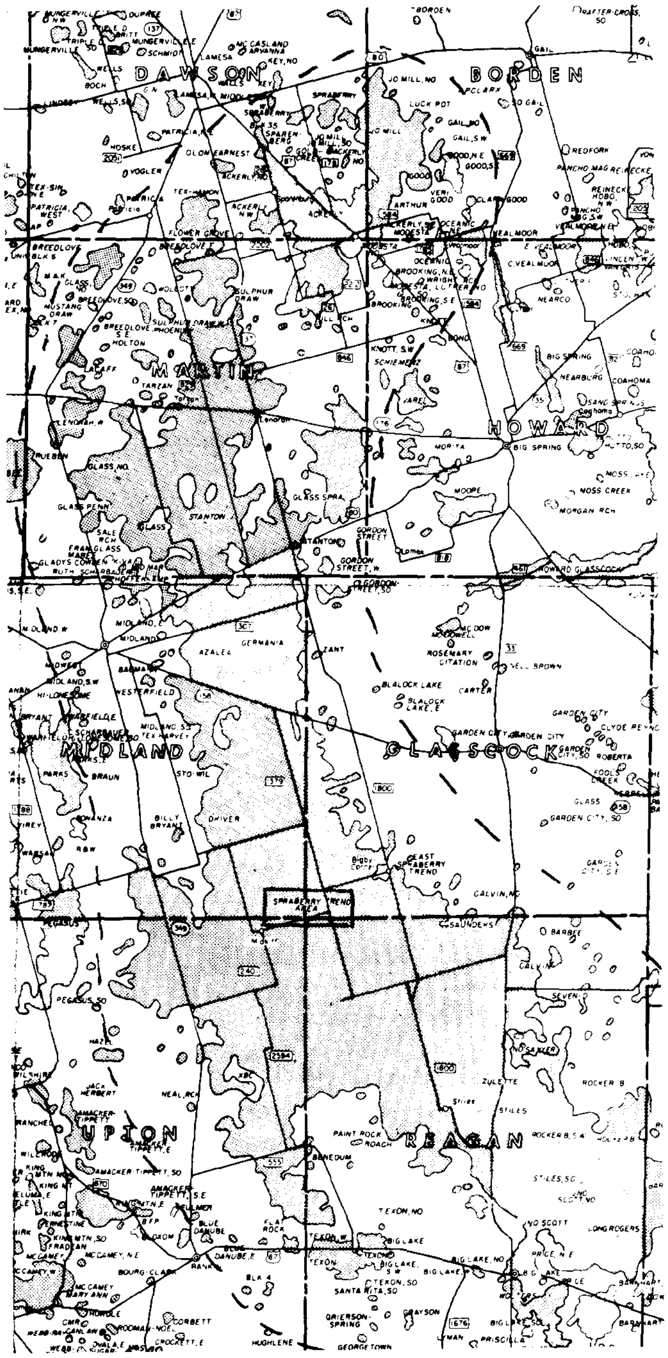

FIG. 1—SPRABERRY TREND AREA

service, hydraulic fracturing.

The completion procedure used on the early wells was to set casing on top of the Upper Spraberry and complete only this top zone from open hole. Many of the wells came in natural for high potentials. Whenever additional stimulation was needed, the open-hole section was shot with large quantities of nitroglycerin. Clean-out operations following these shots were usually long and costly. Attempts to increase productivity with acid treatments were generally unsuccessful.

Hydraulic fracturing[1] was in its infancy at this time. A few small jobs using gelled kerosene with low quantities of sand were tried in the Spraberry and produced immediate, successful results. Almost overnight it became standard procedure to stimulate wells with one or more small pre-mixed batches of gelled kerosene containing ± 1/2 ppg graded Ottawa sand. Suddenly, the hydraulic fracturing technique grew from a few scattered jobs to a full-blooming, everyday service. It soon became evident that larger "frac" jobs produced better results. Shortly, the technique of continuously mixing and pumping the sand-laden fluid was developed, permitting large-stage jobs to be conducted. The next step was to search for a more economical fluid. Viscous refined oils, lease oil, and gelled crude oils were being used routinely by the mid-1950's.

By the end of 1952 the number of producing wells had grown to about 2250, but a disturbing fact had emerged—Spraberry production declined so rapidly that it appeared most wells would never pay out. The boom was over. The Spraberry became a graveyard of dashed hopes and was being called the world's largest reserve of unrecoverable oil. Then came an almost final blow. The flaring of casinghead gas was banned. Production fell to almost nil during 1953 while gas-gathering facilities were installed; and many producers simply ceased operations in the area.

In the middle 1950's secondary recovery units were formed and several different approaches to waterflooding were instituted. It soon became evident that the Spraberry was going to be difficult to successfully flood. A review[2] of the situation in 1964 showed almost 225,000 acres under waterflood. The different methods being tried were: imbibition, water-cycling, balanced low-pressure injection, and balanced injection at high pressure. Generally, the attempts to waterflood were considered unsuccessful and most of the units have now been broken up and the wells returned to their original owners.

The late 1950's and early 1960's brought renewed attention to improved fracturing methods. Many old wells were given a "Max-Frac" type of treatment. This entailed pumping large quantities (100,000 - 200,000 gal.) of slick water containing one pound of sand per gallon and injected at rates in the range of 100-200 BPM. Some favorable results were obtained, but this technique was not considered economically successful.

The middle 1960's saw the beginnings of the rebirth of general industry interest in the area. Whereas most of the early wells had been drilled to the Upper and Lower Spraberry, it was discovered that the Dean zone over much of the area contained reserves that were just as good or better. Programs to deepen old wells were successfully completed throughout the Trend. Naturally there were some problems, but the use of modern completion techniques provided for substantial improvement in lease recoveries at relatively low costs. The Railroad Commission ruled the three zones as being a common reservoir resulting in downhole commingling. This ruling helped the economics and made possible some work on otherwise marginal or noncommercial projects.

At about the same time, funded drilling programs were becoming popular. The Spraberry Trend offered some unique benefits for this type of program. It covered a large areal extent, and even though there were differences in zonal development from well to well, the recoveries were fairly predictable when considering several wells in an area. This enabled the funded operators to make good estimates of the return on investment with a minimum of risk. The people investing in the funds received short-term tax shelters and usually a good long-term return on their investment. These operators were usually developing large blocks of acreage. They made in-depth studies of the various techniques and fluids available, and then developed standard programs for the entire project. Many of the methods in use today were developed at this time.

The increased demand for oil and the new price structure introduced in late 1973 caused the industry to review this area in a new light. The end result was yet another increase in activity with this now being one of the most active areas in West Texas. At the present time there are over 5800 active wells producing in excess of 2,250,000 BOPM.

This brief historical scan of the Spraberry Trend hopefully points out the importance of carefully planning the completion of wells in this area.

GEOLOGICAL CHARACTERISTICS

The Spraberry Trend Area (Fig. 1) blankets the central part of the Midland Basin, a geological province of the Permian Basin[3]. The Trend lies in a general north-south direction and is approximately 150 miles long with a width of approximately 80 miles at the widest portion. Regionally, the zones of interest dip to the north and west.

The Spraberry and Dean sandstones are generally considered to be of the Lower Leonard group. However, early in the exploration of these zones it was reported that Wolfcamp fusulinids were found in the limestone between the Spraberry and Dean sandstones and underlying the Dean in several wells[4]. Regardless of the age of the two, the Lower Spraberry rests conformably on the Dean and the overall interval is reasonably consistent in thickness.

Overlying the Spraberry formation is 5000-8000 feet of rocks, depending on the structural position. Members of the Clearfork group, which directly overlies the Spraberry, are fractured similarly to the Spraberry rocks and provide an excellent marker. The complete interval from the top of the Spraberry to the base of the Dean varies from 1200 to 1800 ft in the Trend Area. However, over short distances the intervals vary only slightly even though there may be considerable differences in the development of the better sand bodies from well to well.

The Spraberry section is generally divided into three zones. The Upper Spraberry covers ±350 ft. It will contain 30-90 ft of coarse-grained siltstones interbedded with fine siltstones, shales, and argillaceous limestones. As one moves to the edges of the area this zone is the first to disappear. The Lower Spraberry interval covers ±400 ft and will have overall producing intervals of ±150 ft. It is quite similar lithologically to the upper zone. Between the two zones lies ±450 ft of thin siltstone beds, shale, and silty shale. This Middle Spraberry is not normally productive. The interval to the base of the Dean accounts for another ±400 ft to the overall interval.

These productive formations are generally called sandstones; however, their grain size mostly falls into the silt range and should correctly be referred to as siltstones. The matrix permeability is consequently very low. Many core analyses of the matrix have shown almost all of the cored section to have less than 0.01 md permeability. Even the best-developed zones in the heart of the Trend rarely exhibit over 0.05 md. With such low matrix permeabilities, the question is immediately raised — how can such a zone show such good potentials and productivities? The answer lies in the existence of the many naturally occurring fractures.

In the early development period, many wells had casing set on top of the Upper Spraberry. Much of the zone was then cored in an attempt to learn more about the reservoir. The recovered cores were badly fractured and would fall apart into sections when removed from the core barrel. Occasionally, cement would be found in the fractures of a core a hundred or more feet below the casing point. Bottomhole pressure interference tests between wells and between zones proved the lateral and vertical extent of the fracturing. In addition, the very high initial potential followed by a very quick decline strengthened the conclusion that the fracture system was the key to the major portion of the recoverable reserves.

Confronted with such a zone, the key to a successful completion is to create a deeply penetrating major fracture system and adequately prop it open. Thus, all the myriad small, incipient cross-fractures can drain into the "pipeline" fracture; and, subsequently, fluids can move to the well bore.

ZONE SEPARATION

When working with multiple zones covering so lengthy a section, it is highly desirable to separate the zones and give each a stimulation treatment specifically designed for it. There are several factors that make zonal separation difficult in the Trend. The bottomhole fracturing pressures (BHFP) of the three zones vary widely. The Dean has a BHFP of 800-1500 psi higher than the Lower Spraberry, and there is a 400-750 psi difference between the Upper and Lower zones. This differential pressure is applied to the cement and formation in the blank intervals between zones. Therefore, if this blank is insufficient in length or competence, communication will occur between zones.

Working in direct opposition is the strong desire of many to perforate in such a manner as to expose all the potentially productive zones within the overall interval to the stimulation treatment. Most operators place one or more perforations in each interval of interest within a zone. The subsequent perforation restriction during the treatment causes the fluid to be distributed over the entire interval (limited entry). The intrinsic fractures present will usually cause the induced fracture to grow outside the perforated interval in an unpredictable manner. Therefore, it is usually the custom to leave in excess of 100 ft of blank interval between zones to be isolated for selective stimulation.

Mechanically, the zones can be separated and treated with conventional packer and plug methods. However, a popular "ring and bomb" system was developed for the Spraberry, and it provides some real advantages over other methods. Figure 2 is a sketch of the system showing the ring at the bottom with the retrievable bomb at the top. In practice, the ring or rings are installed in the casing between joints in a collar at the time the casing is run. The spacing of the rings is determined from open-hole logs or correlation with nearby wells. Exact placement is not too critical in that there is usually more than 100 ft between the planned perforated intervals. These rings are made of cast iron and can be drilled out if desired. When two rings are run for a three-zone completion, the upper ring is enough larger to permit a bomb to be run through it to the bottom, smaller ring. Table 1 gives the inside diameters of the rings for two common casing sizes.

TABLE 1—INTERNAL DIAMETERS OF RINGS

Casing Size	Lower	Middle	Top
4-1/2″	3.50″	3.0625″	2.6500″
5-1/2″	4.00″	3.5000″	3.0625″

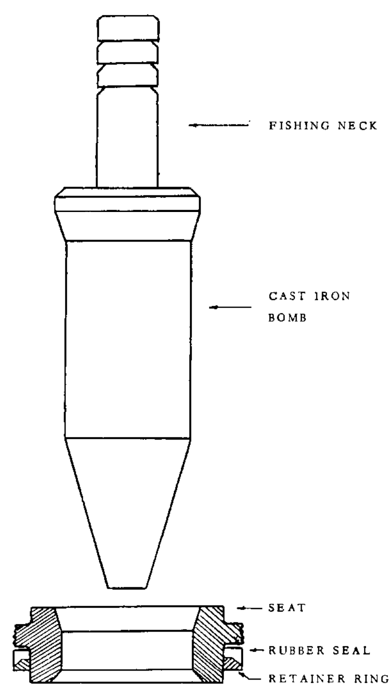

FIG. 2—CAST IRON CASING RING

After the casing has been run with the rings in place, it is common practice to spot acetic acid over the bottom interval at the time the cement plug is pumped. At completion time the bottom zone is broken down via the casing and 15% acid containing ball sealers is pumped to assure that all perforations are open. The acid can be flushed with the pad fluid to be used on the subsequent frac job. After the ball sealers are surged off and allowed to fall to bottom, the stimulation treatment is resumed and conducted via the casing. When flushing this treatment stage, 15% acid is spotted over the next interval up the hole.

The next higher interval is then immediately perforated under pressure. Usually, the existing higher shut-in pressure from the lower zone is sufficient to break down this interval. A quick pump-in test is conducted to determine if the upper zone is now open. Where a pump-in test reflects a sufficient difference in fracture pressure between two successive zones, upper zone frac is commonly performed without using the bomb. Some operators are now routinely leaving out the ring between the Dean and Lower Spraberry. If necessary, the bomb is run on the bottom of a perforating gun and seated in the ring, at the same time shearing the run-in pin. Now the stimulation treatment can be conducted via the casing.

If a third interval is to be stimulated, acid can be spotted during the preceding stage flush and the completion continued as above. The bomb is customarily retrieved with the wire line soon after completion of frac stage in the upper of two separated zones.

The advantages of the ring and bomb method are:

1. Positive separation of zones in a known and planned sequence
2. Permits the stimulation to be conducted via the casing
3. Allows each zone to be given a specific treatment
4. Inexpensive
5. Fast
6. Minimizes the differential pressure across the blank interval.

FRAC FLUID SELECTION

There are several fluids now being used in the area. Each has certain advantages and disadvantages. Following is a summation of the more popular stimulation fluids.

Refined Oil — A viscous oil (19-21° API) that has been refined with the light ends being removed.

1. Advantages
   a. Low net cost
   b. Efficient frac fluid, especially when containing a fluid-loss additive
   c. Provides good sand transport
   d. Produces moderate frac widths
   e. Creates no fluid-formation incompatibility problems
   f. Widely used
2. Disadvantages
   a. High initial cost
   b. Poor pumping characteristics due to high friction losses, especially in small-diameter conductors
   c. Limited availability at times

Polyemulsion — An emulsion containing 65 - 70% lease crude and 30-35% gelled water; breaks by adsorption of the emusifier by the formation matrix.

1. Advantages
   a. Very efficient frac fluid
   b. Excellent sand transport
   c. Good pumping characteristics
   d. Return fluids have low viscosity
   e. Moderate net cost
2. Disadvantages
   a. High initial cost
   b. Slow clean-up at times
   c. Requires special care to prepare properly
   d. Some water disposal cost

Superfrac — A dispersion of refined oil and brine (67-33 mix), pumped with a treated water ring for friction reduction.

1. Advantages
   a. Very efficient frac fluid
   b. Excellent sand transport
   c. Good pumping characteristics
2. Disadvantages
   a. High preparation and net costs
   b. Slow to clean up, especially on weak wells: oil-treating problems
   c. Frequent sand recovery problems during the clean-up period
   d. Some water disposal cost

Gelled Water — 2% KCl or bring water gelled with guar gum.

1. Advantages
   a. Excellent pumping characteristics
   b. High hydrostatic head, low surface

pressure

c. Base fluid readily available
d. Safe to pump

2. Disadvantages
   a. High cost
   b. Added cost due to load disposal problem
   c. Below-average sand transport characteristics
   d. Possible fluid-formation incompatibility

Crosslinked Guar Gum System — Usually prepared with 2% KCl water.

1. Advantages
   a. Total sand suspension
   b. Good pumping characteristics
   c. Base fluid readily available
   d. Safe to pump
2. Disadvantages
   a. High cost
   b. Water disposal costs added
   c. Possible incompatibility with formation
   d. Low tolerance level to base fluid contaminants

A survey was made of approximately 1500 frac jobs conducted over a four-year period in the Spraberry Trend area. Statistics based on number of jobs are: Refined Oil — 85%, Polyemulsion — 3%, Superfrac — 3%, Gelled Water — 8%, Crosslinked Guar — 1%.

ENGINEERED STIMULATION DESIGN

There are several steps generally followed in preparing an engineered stimulation design:

1. Predict the pumping rate versus surface pressure in order to select an injection rate.
2. Make a mathematical model study of frac fluid volume versus penetration (or fracture area).
3. Determine the size and quantity of sand, based on laboratory data, and calculate the conductivity contrast - WK_f/K.
4. Make a plot of cost versus penetration (expressed as L/r_e).
5. Relate L/r_e and WK_f/K to obtain folds-of-increase (J/J_0), then plot cost versus J/J_0.
6. The design features are normally selected at this point; however, further sophistication can be utilized in making a return-on-investment study using discount rates for the investment, current price for the production (less royalty), and predicted production versus time.

The same steps can be used if it is desired to compare several different frac fluids. Also, in the situation under consideration, the study should be extended to include the several zones to be stimulated.

In order to illustrate these procedures a composite Spraberry Trend well was created using some general average values as follows:

	U. Spraberry	L. Spraberry	Dean
Top	6700 ft	7500 ft	8000 ft
Perf	6800-6850	7550-7700	8100-8300
Zone H	50'	150'	200'
Est. BHP	2450 psi	2740 psi	3280 psi
Gradient	.36 psi/ft	.36 psi/ft	.40 psi/ft
Est. BHFP	3480 psi	4040 psi	5170 psi
Gradient	.51 psi/ft	.53 psi/ft	.63 psi/ft
Porosity	9%	9%	8%
Permeability	0.5 md	0.5 md	0.3 md
$E \times 10^6$	1.85 psi	1.85 psi	3.32 psi
Oil Viscosity	1.0 cps	0.9 cps	0.7 cps
Comp $\times 10^{-5}$	1.3 psi^{-1}	1.3 psi^{-1}	1.2 psi^{-1}
Est. BHT	131°F	138°F	142°F

NOTE: Porosity and permeability have allowance made for natural fractures.

This information was used to make a comparative study of three fluids: Refined oil, polyemulsion, and crosslinked gelled water.

1. Figures 3, 4, and 5 depict the injection rate versus surface pressure based on 4-1/2 in. casing.
2. Figures 6, 7, and 8 show the results of fracture computations using the reservoir data, fluid characteristics, and injection rates of: Dean - 20 BPM, L. Spraberry - 25 BPM, U. Spraberry - 30 BPM.
3. Laboratory studies indicate that the optimum sand concentration for all three formations is ± 0.6 lb/ft² of fracture area. Calculated conductivity contrasts are:

	40-60	20-40	12-20
Dean	4.0×10^4	1.4×10^5	1.68×10^5
L. Spraberry	2.4×10^4	9.0×10^4	1.15×10^5
U. Spraberry	2.4×10^4	9.6×10^4	1.39×10^5

For 160-acre spacing a contrast of 1.0×10^5 is considered to be adequate, and at this point it is considered better to spend money for obtaining penetration rather than a higher contrast. Therefore, 20-40

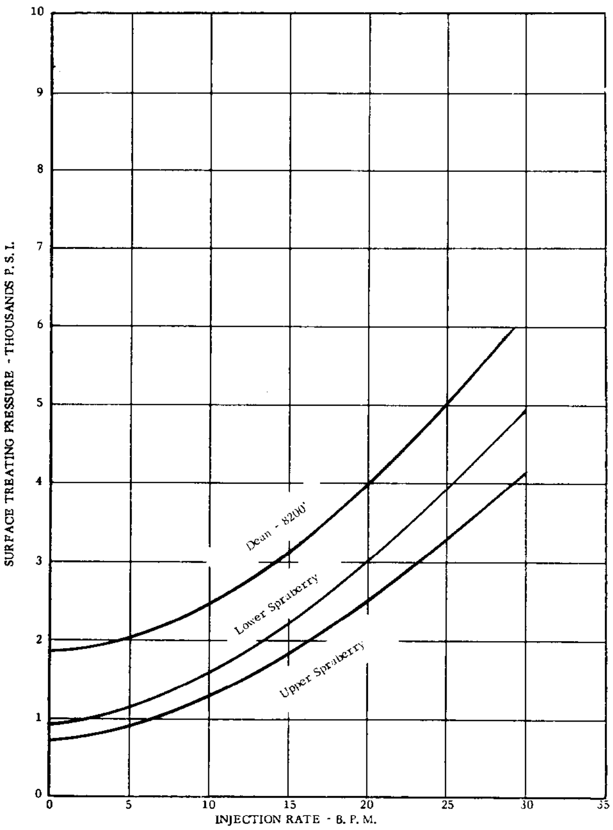

FIG. 3—REFINED OIL — 4-1/2 IN. CASING

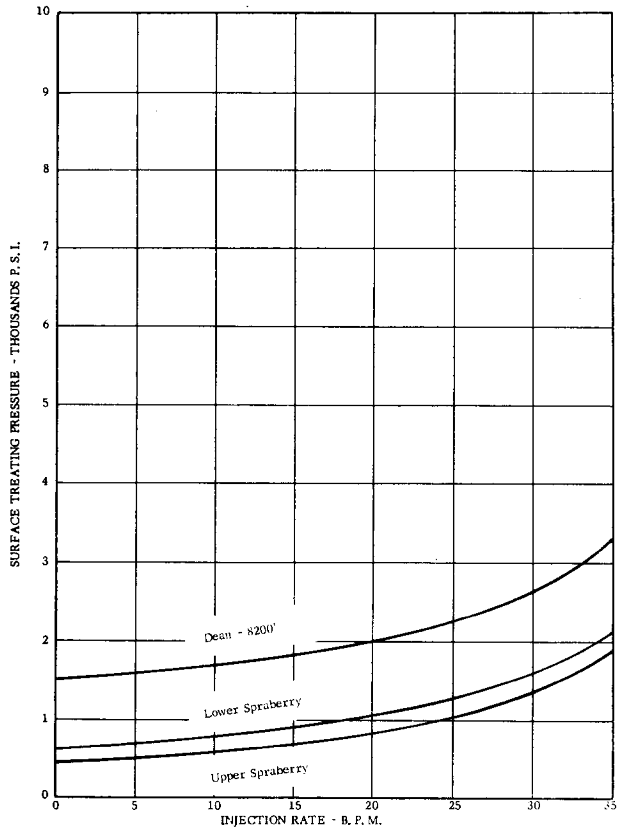

FIG. 5—CROSSLINKED GEL WATER — 4-1/2 IN. CASING

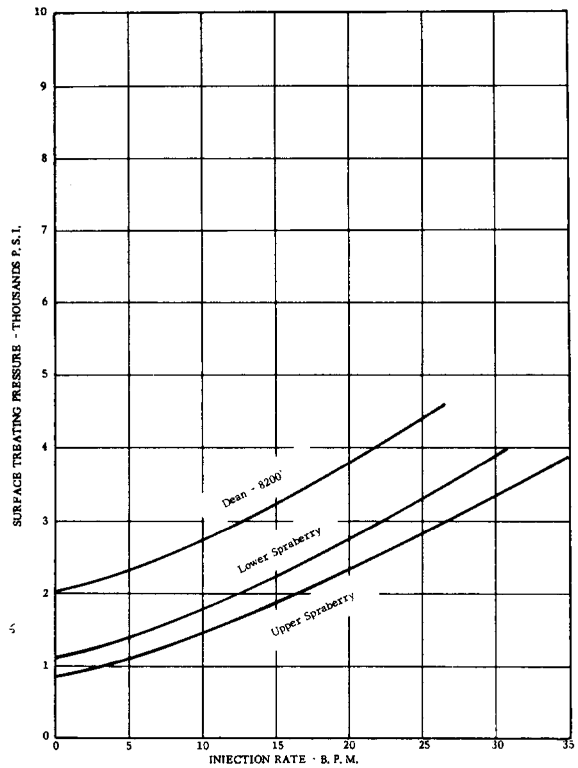

FIG. 4—POLYEMULSION — 4-1/2 IN. CASING

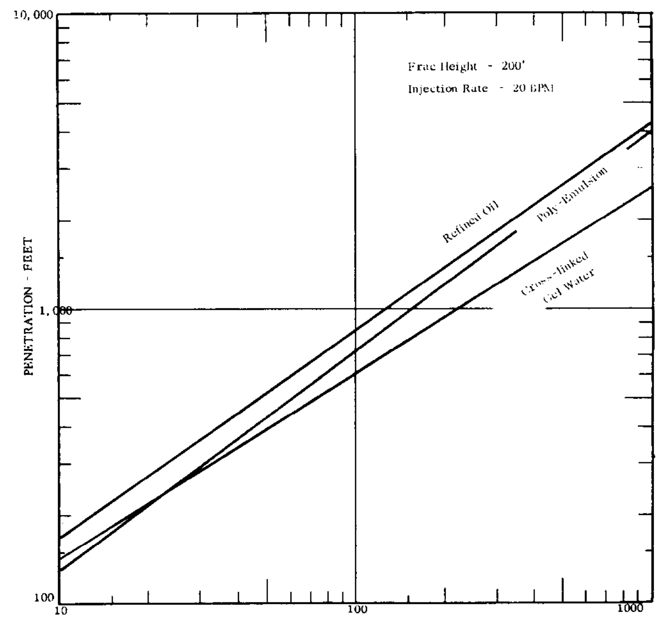

FIG. 6—FRACTURE PENETRATION — DEAN

mesh sand was chosen for all three zones.

A tabulation of costs versus L/r_e is depicted in the lower part of Figs. 9, 10, and 11. The costs were computed on present prices. They include horsepower, blending, net fluid costs (cost less resale of oil used), sand, fluid-loss additives, chemicals, flush fluid, and royalties. NOTE: The costs are based on using a 2% KCl solution for the water phase of the polyemulsion and to prepare the crosslinked gelled water.

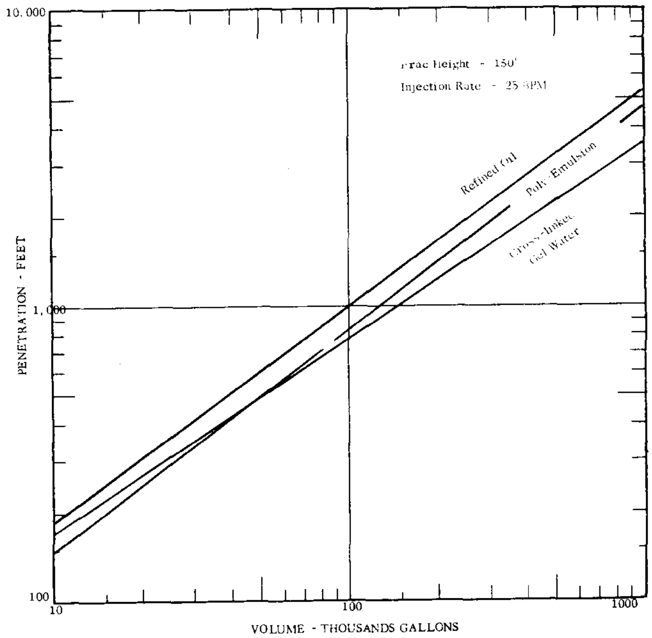

FIG. 7—FRACTURE PENETRATION — LOWER SPRABERRY

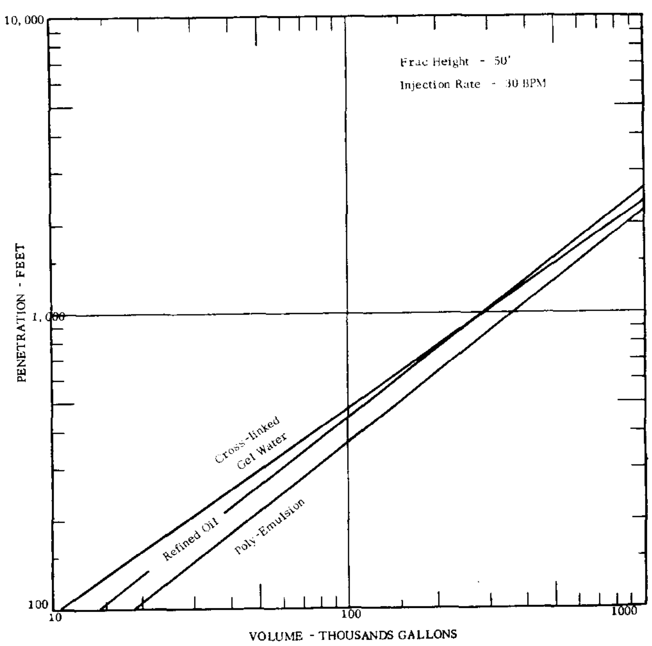

FIG. 8—FRACTURE PENETRATION — UPPER SPRABERRY

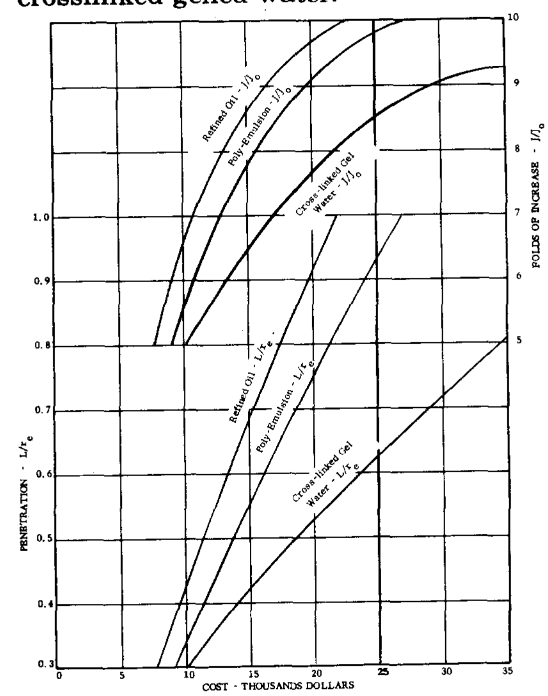

FIG. 9—COST STUDIES — DEAN

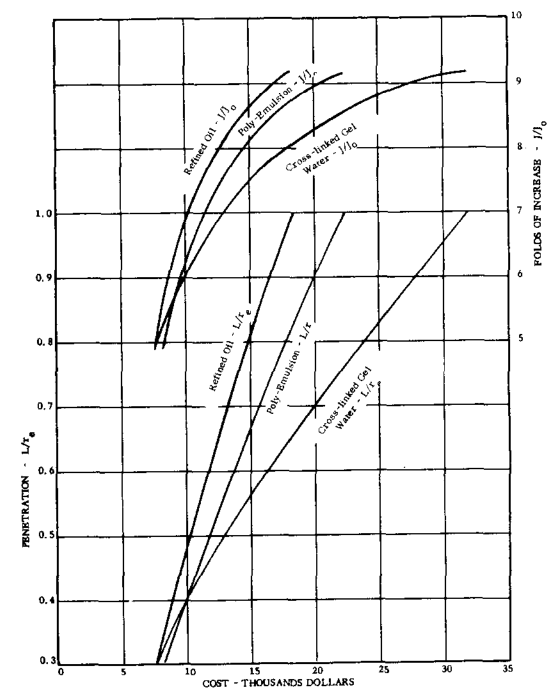

FIG. 10—COST STUDIES — LOWER SPRABERRY

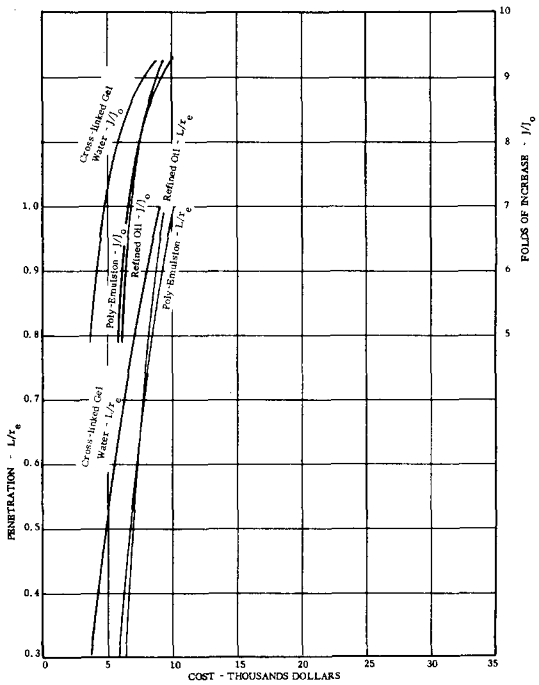

FIG. 11—COST STUDIES — UPPER SPRABERRY

5. Using the above costs, and relating the L/r_e to folds of increase, a plot was made of cost versus J/J_o. These plots are shown in the upper portion of Figs. 9, 10, and 11 permitting ease in coordination of the information. Folds of increase are based on McGuire and Sikora[5].
6. Visually inspecting Fig. 9 for the Dean shows refined oil to be the preferred fluid. It appears that the J/J_o curve begins to flatten out at about $15,000 cost. Checking the lower curve this will provide an L/r_e of 0.7, or 924-ft penetration for 160-acre spacing. Referring to Fig. 6 it will require approximately 120,000 gal. of fluid. Based on 0.6 lb sand/sq ft for the 364,000 sq ft of fracture area, a total of about 220,000 lb of sand are needed.

The Lower Spraberry of Fig. 10 also shows refined oil to be the choice. The J/J_o curve changes slope at about $12,500 for a L/r_e of 0.65, or 858-ft penetration. This will require 80,000 gal. fluid containing 155,000 lb sand for the 247,400 ft^2 of fracture area.

Fig. 11 for the Upper Spraberry indicates crosslinked gelled water to be the choice if this zone were treated alone. However, it presents a problem if all three zones are to be treated on one set-up. In that the programs were worked up for only one rate for each zone, a lower rate of 25 BPM for this zone was checked. At this rate the refined oil more nearly approaches the crosslinked gelled water. Using refined oil at 25 BPM, the J/J_o curve changes at about L/r_e of 0.8 requiring 36,000 gal. fluid and 64,000 lb sand.

The above comparative study was made on fluids. A similar approach can be followed to study the specific effects of the various design factors on a single fluid. It should be noted that such mathematical studies produce information that is no more accurate than the input information. In that such input as fracture height can make big differences in the volumes required, the information developed should not be used as absolute numbers. However, when used for comparative studies mathematical models are very useful.

PRODUCTION STUDIES

The above engineering approach is based on ideal reservoirs. In that the Spraberry-Dean siltstones depart drastically from the ideal due to their fractured nature, it behooves us to review production data in evaluating stimulation treatments. However, this approach is also fraught with traps. In comparing production, the wells being compared must be producing from the same intervals, and these zones must be fairly equal in quality of development. Several statistical studies have been made of selected areas. Such a study was made in the Ackerly Dean Field as shown in Table 2. All these wells were stimulated with refined oil at about 20 BPM. It will be noted that with larger treatments greater recoveries were obtained.

TABLE 2—PRODUCTION VS. STIMULATION VOLUME ACKERLY DEAN FIELD

Frac Volume Gal.	Number Wells	Average Prod. Period - Years	Cumulative Prod. per well
30,000	7	8	36,146
40,000	3	9	40,816
50,000	2	5-1/2	36,816
60,000	1	5	38,421
80,000	15	4-1/2	42,880
100,000	7	4-1/2	44,925

Sand transport and sand size has been the subject of several studies. Generally, the combination of fluid properties and sand size used in the Trend provides for excellent sand transport. There has been some thought given to using fine sand in the first part of the treatment and grading up toward the end — the reason being that small "feeder" fractures may be opened just wide enough to accept the fine sand, but not the larger sand. Since the flow of fluids in a fracture is a function of the width raised to the third power, small increases in width will theoretically provide for significant increases in production. In a recent development program by an operator in the Sulphur Draw (Dean) Field, the stimulation program was slightly changed during the program. Five of the wells are in one small area on offset locations. One of the "experimental" wells is actually between two "regular" wells. Production information was kept on each separate well. Overall, this represents very good control for production studies. Figure 12 is a plot of production from three wells (D, E, and F) which were treated with 80,000 gal. refined oil and 160,000 lb 20-40 sand at 15 BPM. For all practical purposes, decline curves are identical. The next well (G) was treated with 100,000 gal. refined oil using 20,000 lb Oklahoma #1 Fine (80-120), 40,000 lb 40-60 sand, and 70,000 lb 20-40. The next well (H) was treated in the same manner except that the rate was raised to 22 BPM. Figure 13 is a plot of production from a "regular" well (D) and the two wells with the increased volume using fine sand. The middle curve is at 15 BPM, and the top curve is at 22 BPM. It will be noted that longer flush

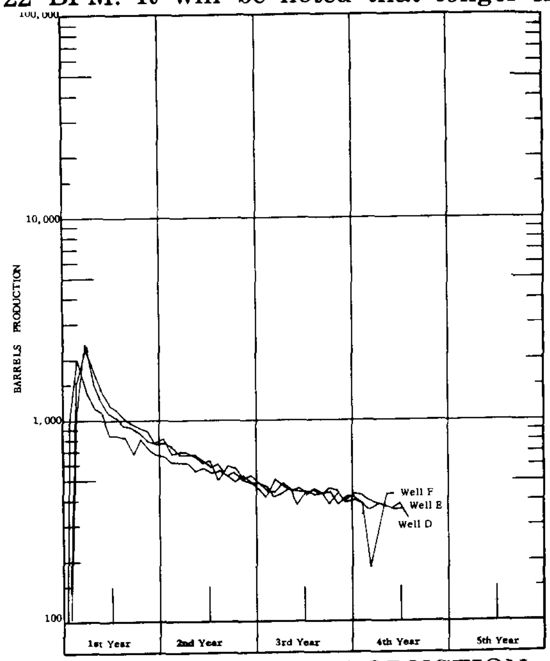

FIG. 12—MONTHLY PRODUCTION

periods are exhibited by the two wells with the graded sand program. Production data in other areas from wells that were treated with staged sand sizes have generally shown the same characteristic.

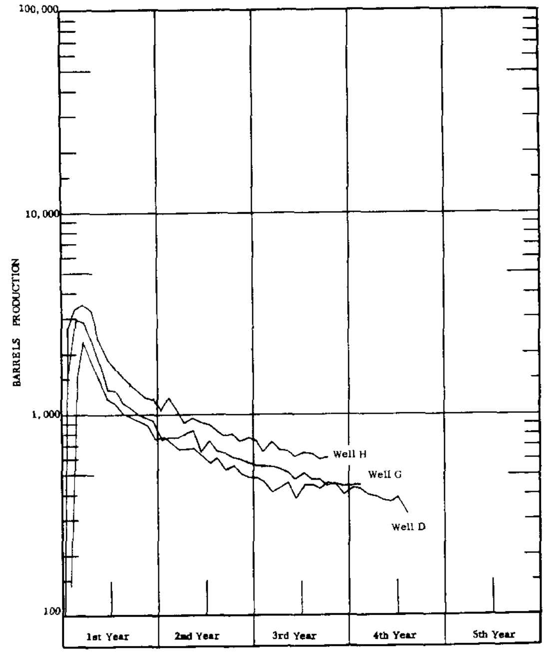

FIG. 13—MONTHLY PRODUCTION

There is constant search for improvement. Presently there are several innovations being tried: staging the sand in slugs, reduced rates to reduce the tendency for the frac to grow out of zone, very large volume treatments, and higher rates with pseudo-plastic fluids to reduce fracture widths. It will require some time and good historical production information to pick the winners.

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