FEATURE ARTICLE

Hydraulic Fracturing in the Caddo-Pine Island Field

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Abstract

The application of the hydraulic fracturing process in the Annona Chalk formation in the Caddo-Pine Island field, Caddo Parish, La., has created a new outlook on the development of this reservoir as an economic source for oil production. The reservoir has been greatly affected by faulting and/or fracturing during its geologic history, and the physical characteristics of the formation have made possible the successful hydraulic fracturing operations. These conditions have also caused the production to vary greatly between wells and have resulted in several different methods of drilling and completion practices by the operators.

This paper describes briefly the geology, development history, present drilling and completion practices, and the results of the hydraulic fracturing process in stimulating the production from this reservoir. In order to show results of the various completion techniques, production histories on several wells are presented and comparisons of the production from individual or groups of wells before and after fracturing operations are discussed.

Introduction

The Caddo-Pine Island field is located approximately 15 miles north of the City of Shreveport in Caddo Parish, La., and Marion County, Tex., and is shown geographically in Fig. 1 which covers a portion of the Ark-La-Tex Area. Although production has been obtained from several horizons, ranging in depth from the Nacatoch sand at 800 ft to the Hosston or Travis Peak which is found at 2,500 ft near the crest of the dome of the Lower Cretaceous beds, this paper will deal mainly with the development and production of the Annona Chalk reservoir.

The production from the Chalk is associated with faulting and natural fracturing of the formation and is found in several fields in North Louisiana. The discovery well in the Caddo-Pine Island field was the Savage Bros. & Morrical No. 1 Offenhauser, which was completed March 28, 1905, in the Annona Chalk at a depth of 1,556 ft. The well was located near Oil City, La., in the center of the NE ¼ of the SW ¼ of Sec. 1, T20N, R16W, and had an initial production of 5 B/D of 34° gravity oil. The well was considered non-commercial by the operators and was soon plugged and abandoned. However, this discovery led to further development. By the close of 1907 23 wells had been drilled—eight of which produced oil, 11 produced gas, and four were abandoned. Development of the field continued at a rapid pace during the following years, and by 1918 the production reached a peak of 11 million bbl/year.

Size of Field

The producing limits of the Caddo-Pine Island field are shown in Fig. 2 which includes the Chalk producing limits and the major Oil City fault. The outer limit covers

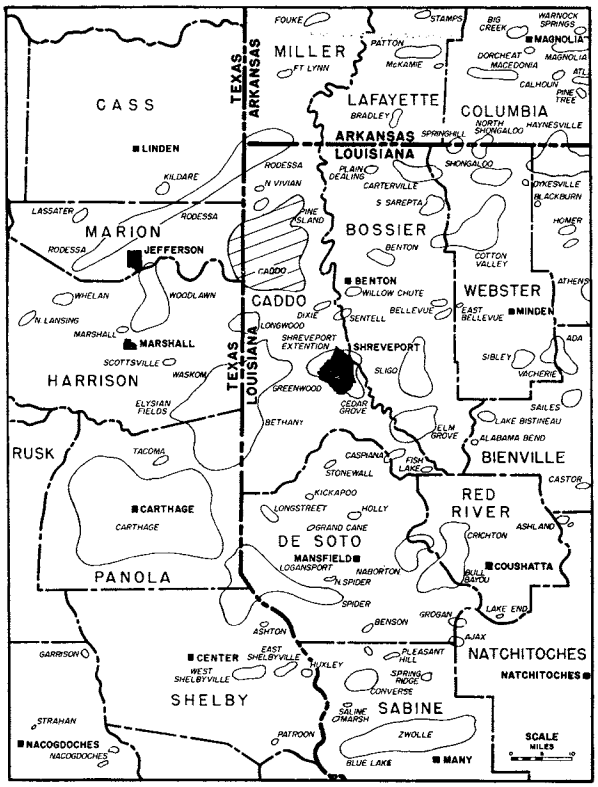

Fig. 1—Location of Caddo-Pine Island field.

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all producing reservoirs in the field. The Caddo-Pine Island field is the largest oil producing area in the State of Louisiana, covering roughly 80,000 acres on which more than 9,000 wells have been drilled during the past 50 years with an accumulative production of over 200 million bbls of oil. The present field productive area is considered to be 36,000 acres with a total of 4,882 producing wells, 366 different operators, and 1,161 individual producing tracts. The most prolific producing wells were completed in the Paluxy sand, commonly called Woodbine, during the early development of the field, but rapid depletion of the reservoir occurred because the production was not restricted and the wells were allowed to produce at their maximum capacity.

The characteristics of the Chalk, as will be shown later, controlled the withdrawal rates from this horizon and sufficient oil remained in place to encourage later development as completion techniques were improved. The productive area of Chalk prior to hydraulic fracturing operations was approximately 10,000 acres, but the present extended limits of Chalk production covers nearly 20,500 acres. The average spacing of the Chalk producing area is 5 acres per well, but many wells have been drilled on town lots and on closer spacing in the better producing areas of the Chalk.

Results of Intense Drilling

Intensive drilling in the Chalk started after the successful application of the fracturing process; and from the first treatment during Jan., 1953, to July 1, 1955, 1,510 wells were completed and a great many wells recompleted by this method. In the extended Chalk producing limit there are 298 different operators, 905 individual tracts and 4,035 producing wells. The drilling of new wells and recompletion of the older wells still continue at a rapid pace.

To compare the production and number of wells at the start of fracturing operations with the present status, two two-months' periods were selected to obtain a monthly average and the results are as follows.

	Caddo-Pine Island Field			Chalk Producing Area		
	No. Wells	BOPM	Daily Avg. Per Well	No. Wells	BOPM	Daily Avg. Per Well
Jan.-Feb. '53	3200	379,407	4.0	2525	264,904	3.5
June-July '55	4882	730,211	5.0	4035	583,067	4.8

Production History

The peak production of 11 million bbl/year in 1918 had decreased to 1,606,424 bbl in 1936. A gradual increase then occurred as a result of increased drilling activities and acid treatments so that by 1947 the annual production was 2,228,000 bbl. Increased drilling activities during 1953 and 1954, along with hydraulic fracturing of both the new and old wells, resulted in an increase of production to 5,434,578 and 8,143,496 bbl for the respective years. Based on the average production for the two-months' period above, the production for the Chalk wells alone reached approximately 7 million bbl in 1955.

The Caddo-Pine Island field is classed as a stripper producing area; therefore, it is important that every cost in drilling, completing, and operating the wells be held to an absolute minimum. The price obtained for crude oil from the field has played an important part in the recent development, and is reflected in the increased drilling activities since 1946.

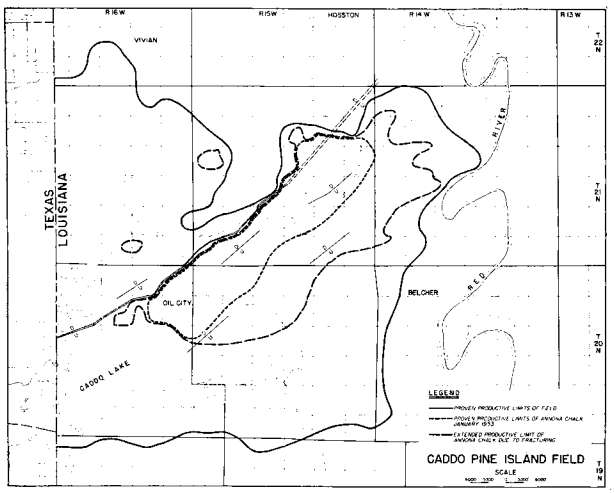

Fig. 2—Producing limits of field.

General Geology and Physical Characteristics

The Caddo-Pine Island producing area is associated with a dome relating to and on the northern flank of the Sabine Uplift. The structure is a graben type completely faulted dome with over 2,500 ft of closure on the Ferry Lake Anhydrite. The primary uplift occurred at the close of the Lower Cretaceous period, was then followed by erosion and later by the encroachment of the Upper Cretaceous seas. The crest of the structure on the Lower Cretaceous beds is located in Sec. 14, T21N, R15W.

The initial sediment of the Upper Cretaceous was the Eagleford Shale and was followed by the deposition of the Tokio, Ozan, Annona, Marlbrook, Saratoga, Nacatoch, Arkadelphia, Midway and Wilcox formations. The Midway and Wilcox are Eocene in age. Subsequent to the deposition of the Upper Cretaceous beds, the dome experienced additional uplift and the crest of the dome on the Annona Chalk was shifted to the southwest in the vicinity of Oil City, La.

Oil City Fault

The major accumulation of oil in the Chalk is found on the south up-thrown side of the Oil City fault and as shown in Fig. 2 this fault has been extended across the dome of the Lower Cretaceous beds by dashed lines because sufficient control is not available to definitely locate the fault in this area. Also shown are several of the numerous small en-echelon, down to the north, epidomal, normal faults which locally control the more prolific accumulations of oil in the Annona Chalk. The Chalk is productive between a subsea depth of 1,300 to 1,470 ft. In the main producing area, however, a large portion of the southern flank of the dome is unproductive although the Chalk is found above a subsea depth of 1,470 ft. Minor Chalk production is found within the graben on

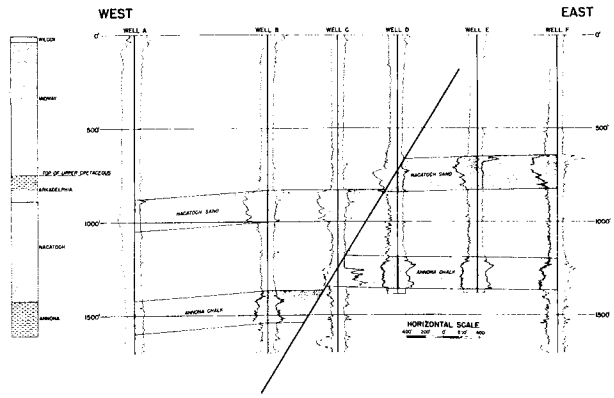

Fig. 3—West-east cross-section A-A′ showing throw of major fault.

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low-relief closures associated with down to the north faults in the area of Shoreline and Trees City as shown in Fig. 2 by the small encircled areas west of the major faults.

A west-east cross-section A-A′, Fig. 3, shows the throw of the major fault which is located near the center of the Chalk producing area. The depths are shown as subsea measurements, and the generalized geologic section on the left shows the Upper Cretaceous and the Eocene beds. The Marlbrook Marl and Saratoga Chalk have been grouped in the Nacatoch section in this illustration.

Formation Characteristics

Although there have been a considerable number of wells drilled in the field, only a limited amount of core data have been obtained and the formation characteristics listed below have been shown to cover the average condition that exists in the Annona Chalk.

Average permeability: Less than 0.1 to 1.5 md
Average porosity: 25 to 28 per cent
Residual oil saturation: 15 to 35 per cent of pore space
Total water saturation: 30 to 60 per cent of pore space but can be as high as 75 per cent and still produce oil
Average pore volume: 1,500 to 2,000 bbl/acre ft
Estimated recovery: 10 to 20 per cent of oil in place
Gas-oil ratio: 1,000 to 1,500 cu ft/bbl
Gravity of oil: 34 to 40 ° API
Average thickness: 185 ft. Average thickness of producing section: 140 to 160 ft
Type drive: Gravity drainage
Drainage area: 1 to 2½ acres

The subsurface pressure data are also very limited in the field, but during the first six months of 1955 pressure tests were made on six wells prior to fracturing and seven wells after fracturing. The wells were selected to give a wide spread in the Chalk producing area and the pressures prior to fracturing ranged from 100 to 200 psig and after fracturing from 300 to 400 psig with limited shut-in periods from five to 12 hours. The original bottom-hole pressure has been estimated at 750 psig.

To show the general characteristics of electrical and gamma ray-neutron surveys of the Chalk section, three wells were selected at random and are presented in Fig. 4. The gamma ray-neutron survey on Well G and electrical survey on Well H penetrate the entire Chalk section. The electrical survey on Well I reflects that a fault had cut through the top zone and approximately 35 ft of the section is missing in this well. The Chalk section has been divided into three zones—the upper, middle and lower—which seem to be separated by chalky shale stringers. For the purpose of defining the zones, only the productive section of Chalk will be considered. The upper, middle and lower zones occur in Well H at depths from 1,449 to 1,511 ft, 1,511 to 1,551 ft, and 1,551 to 1,587 ft, respectively. The three zones are used to describe the present methods of completing and fracturing wells in the Chalk as presented later in the paper.

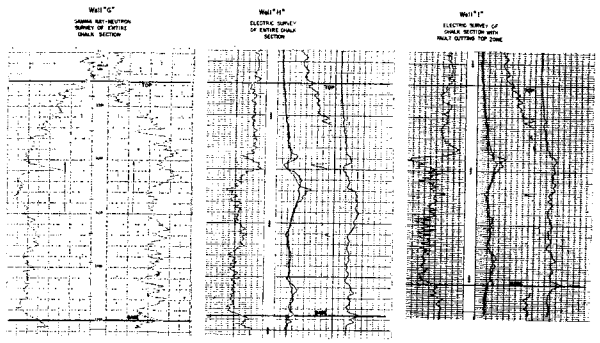

Fig. 4—General characteristics of electrical and gamma ray-neutron surveys of Chalk section, as shown from three wells.

History of Development

The early development of the Caddo-Pine Island field was highlighted by crude rotary drilling equipment, wooden derricks, and frequent blowouts. Attempts were made to locate the wells along the major fault line, but this was difficult until sufficient wells were drilled to define the fault. From early drilling and completion practices new methods and techniques have been developed which now allow the completion of Chalk wells in three to five days as compared with a previously required time of two to 12 months. With the exception of lost returns in the Nacatoch or faulted Chalk section there are no unusual drilling hazards in the field. The setting of surface casing is not necessary if the oil string is cemented to the surface and this practice reduces the completion costs due to the smaller hole size.

Drainhole drilling methods have been used to complete some 30 to 40 wells, but the present results do not indicate that this method is any better than a normal completion. One of the first wells drilled by this method was completed by drilling ten 3¾-in. drain holes ranging in length from 43 to 79 ft with an initial production of 3½ BOPD, pumping. The well was then fractured with 63,000 lb of sand and 500 bbl of oil. The well flowed for two weeks, and four months after treatment it pumped 7½ BOPD and 13 BWPD. Eight months after treatment the well pumped 4 BOPD with no gauge being taken on the water production.

Drilling costs in the field are very reasonable, ranging from $2,400 to $3,000 per well on turn-key contracts and from $2,500 to $3,500 on a footage basis. The drainhole drilling method when used increases the cost per well by approximately $3,500 for four 50-ft holes.

Remedial operations became necessary on the early wells as the Paluxy reservoir was depleted, and methods of ripping the casing opposite the Chalk formation were employed to restore production from the wells. This method of remedial work was effective in wells near the faults and became more widespread after acidizing techniques were introduced in the field. The success of these jobs was dependent upon many variables such as good plugs, natural producing Chalk zones, or proper treatment of a productive section with acid; but sufficient production increases resulted from these recompletions to encourage the drilling of new wells to the Chalk formation.

With improved acidizing techniques the drilling of Chalk wells continued on a limited basis from 1936 to 1942, was suspended during the war years, and was not resumed on a large scale until after the price increase for oil in 1947. Acid treatments were continued in completing the Chalk wells until hydraulic fracturing treatments were started in the first part of 1953. Although the first fracturing job was performed in the Chalk in Jan., 1953, most of the operators continued the acidizing programs until May, 1953, while a successful, economical fracturing process was being developed for the field.

Present Completion and Hydraulic Fracturing Methods

The completion of the Chalk wells can be divided into three general classifications: (1) setting casing on top of the Chalk section and completing in the open hole, (2) setting casing at an intermediate point between the top and base of the Chalk section and completing in the open hole with one or two of the other zones perforated, and (3) setting casing through the Chalk section and perforating the desired zones to be fractured. After casing has been set and the zones selected for production tests, the wells are prepared for fracturing by setting straddle pack-

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ers with hydraulic hold-downs and pump-out subs or with a retrievable bridge plug and packer with hold-down to isolate the zones for treatment. As many as four intervals have been selectively treated without moving the tubing when packers are used to isolate the intervals, and six intervals have been treated with the retrievable bridge plug method during one continuous fracturing operation.

Economical fracturing operations were made possible by local firms supplying bulk sand and operators supplying low gravity lease crude (17° to 23° API gravity) or low gravity (17° API) fuel oil from a local refinery. The equipment furnished by the service company for use in hydraulic fracturing consists of two 325-hp diesel pumps, a blender truck, and mixing tank to emulsify the crude. The process of emulsifying lease crudes introduced in the summer of 1954 has eliminated many of the treating problems experienced with the heavier oils.

Size and Cost of Fracture Treatment

The first fracturing treatment used only 8,000 lb of sand but experience proved larger volumes could be used so that by the spring of 1954 the average job used 40,000 to 60,000 lb of sand and 450 to 650 bbl of oil. The injection rate is 5 to 6 bbl/min with an average pump pressure of 2,500 psig which is necessary to overcome tubing friction. Either round grained sand of 20 to 40 mesh is used or a combination of round grained sand followed by an equal amount of angular grained sand of 10 to 20 mesh. The cost of an average job will range from $2,500 to $3,500 per well. The largest fracturing treatment in the field consisted of 250,000 lb of sand and 2,500 bbl of heavy oil and required eight hours of continuous pumping.

The average treatment is probably a three-zone job in which the zones are broken down with oil before starting the injection of the sand and the tubing is completely flushed with oil between each stage of the treatment. If the zone fails to break down with oil, an acid treatment of 500 gal of regular 15 per cent HCl acid will be used ahead of the sand. After the fracturing process has been completed, the wells are generally left shut-in until the pressure equalizes around 400 psig.

Testing the Fractures

The lower Chalk zone contains the greatest oil saturation and is usually treated with one-fourth more sand than the middle or upper zones in a three-zone treatment. In selectively treating old wells, temporary plugs—usually crushed moth balls—are used to seal off low pressure thief zones; 800 to 1,000 lb of this material will be used in fracturing a well. Spinner surveys have been used in the fracturing operations to locate the point of entry of the material into the formation, and radioactive material has been added to the sand in an attempt to trace the created fracture with a gamma ray survey. Although the points of entry could be located, the distribution of the radioactive sand was very erratic and the results did not justify the additional completion costs because the production from these wells indicated that fractures were occurring in the zones of higher oil saturation.

Various completion procedures were used on one lease to test the possibility of vertical fractures occurring during a treatment, but the results indicated only small variations in the stabilized production from the wells over a 24- to 30-month period. In comparing production from several wells in the field, there does not appear to be any great difference between the daily production from the wells that were treated with an average of 40,000 to 60,000 lb of sand and those completed with larger treatment or by the drainhole technique. However, the formation characteristics are such that each well must be considered individually; and, certainly, there has not been sufficient time to evaluate the results of large treatments and drainhole drilling on the ultimate recovery from the wells.

With the exception of water-fracturing treatments, most of the various methods of hydraulic fracturing processes have been used in the field with no apparent advantage of any one method in fracturing the Chalk formation. The effect of natural fractures near the wellbore still governs the more prolific producing wells, and the results of acid or fracturing treatments are much greater in the area of the field where these conditions occur.

Although some interference with producing wells has been noticed during fracturing operations in densely drilled areas, sufficient data are not available to analyze the interference observed because there is no definite distribution of the forces in the area affected by the fracturing of a well. Sand trouble often occurs in the wellbore and tubing string after a well has been fractured and placed on production, but this trouble is localized and not general for the field. The sand fill-up is usually greatest in the wells that flow after the treatments as there are slugs of sand produced while the wells are flowing. Subsurface pump trouble resulting from the backflow of sand usually lasts from six months to a year in the wells affected but will not generally require a clean-out and is serviced by changing only the pump itself.

Production Equipment and Operating Costs

A brief description of the production equipment is presented to show how the operating costs are controlled. The leases are equipped with 100- or 200-bbl storage tanks, a small heater-treater or gun barrel, 2-in. flow lines and small 3- to 5-hp pumping units. On large leases 300- to 500-bbl tanks are used with 4-in. trunk lines centrally located on the lease and 2-in. lateral lines to each producing well. The pumping units are operated with 3-hp electric motors equipped for time cycle operations which enables as many as 85 wells to be handled by one pumper.

This equipment has been the prime factor in maintaining low operating costs and has been of major importance in the development of the field. The subsurface equipment usually consists of 2-in. tubing, a 1½-in. metal-to-metal pump, and ⅝-in. sucker rods. The power costs range from $5 to $10 per month per well and is roughly 2 to 3 cents per kwh. The flowing periods following the fracture treatment have been extended by the use of surface chokes, time controlled wellhead intermitters, and by automatically controlled free piston installations. Although lower operating costs occur during the flowing period, tests have indicated that the pumping wells generally produce at higher rates from the Chalk. Testing equipment is particularly important in studying the results of fracturing and small 25- to 30-bbl portable test tanks have proved to be the most economical method to obtain the data. These tanks are moved from well to well with a pick-up truck and are equipped with a small electrically driven centrifugal pump to transfer the oil from the test tank to the casing annulus or into the flow line.

Summary of Results of Hydraulic Fracturing

Several production decline and accumulative production curves were prepared on leases and individual wells located in the southern, central, and northern portions of the Chalk producing area, but the results of only one curve in each category will be discussed here. Attempts

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were made to compare only average wells on the leases instead of the better wells so that the general field conditions would be reflected. Also, wells with sufficient production history had to be selected.

Comparison of Acidized and Fractured Wells

The decline curves shown in Fig. 5 compares 10 newly fractured wells on Lease J to eight newly acidized wells on Lease K. The leases J and K are located in the northeast central portion of the Chalk producing area and are in Sections 23 and 27, T21N, R15W, respectively. The fractured wells compared were drilled in 1953 and 1954, with eight of the wells completed by setting the casing on top of the lower Chalk zone and with the other two wells having casing set through the entire Chalk section. There were five wells fractured in all three zones, selectively, and five wells treated in only two sections. Of these latter five wells, three were fractured in the lower and middle zones together and in the top zone separately, and two were fractured in the lower and middle zones separately. The average treatment consisted of 30,000 lb of sand and 350 bbl of oil with a sand concentration of 2¼ lb/gal, an injection pressure of 2,300 psig, final pressure of 700 psig, and an injection rate of 4.5 bbl/min.

The acidized wells compared were drilled in 1948 and were completed by setting casing on top of the middle Chalk zone. The wells were acidized by treating the open hole in the lower and middle zones with 5,000 gal of regular 15 per cent hydrochloric acid. The injection pressure ranged from a vacuum to 450 psig. For the purpose of comparison, all oil used in the fracture treating of wells and later produced has not been included in any tables or on any curves of this report. The daily average production for the wells covered in this comparison is as follows.

	Daily Average Production per Well	
Decline Period	Fractured Wells	Acidized Wells
1 Month	32.7	42.0
6 Months	12.8	7.8
12 Months	10.2	6.1
18 Months	8.2	4.7
24 Months	6.2	3.5

Although the curves indicate a continued decline at the end of the 24-months' period compared on these wells, production histories on the acidized wells show that a stabilized average production per well of 2.5 B/D was reached after five years. The production has remained constant at 2.5 B/D per well for the last four years. Assuming that the fractured wells will decline at the same rate as the acidized wells, the average production for the fractured wells will be approximately 5.0 B/D per well and will then continue at this rate for several years.

Further Comparison of Acidized vs Fractured Wells

The decline curves shown in Fig. 6 compare 10 newly acidized wells on Lease L to the same 10 wells after fracturing. Lease L is located in the southwest portion of the Chalk producing area in Section 1, T20N, R16W. The wells were drilled in 1951 and 1952 and were completed by setting casing on top of the middle Chalk zone. The wells were acidized by treating the open hole in the lower and middle zones with 5,000 gal of regular 15 per cent HCl acid. The injection pressure averaged 350 psig. The wells were recompleted by fracturing in the early part of 1954 and the lower and middle zones were treated together with an average of 30,000 lb of sand and 250 bbl of oil. The sand concentration was 2¼ lb/gal and the average injection pressure was 2,000 psig with a final pressure of 200 psig. The average injection rate was 4.5 bbl/min. The daily average production for the wells covered in this comparison is as follows.

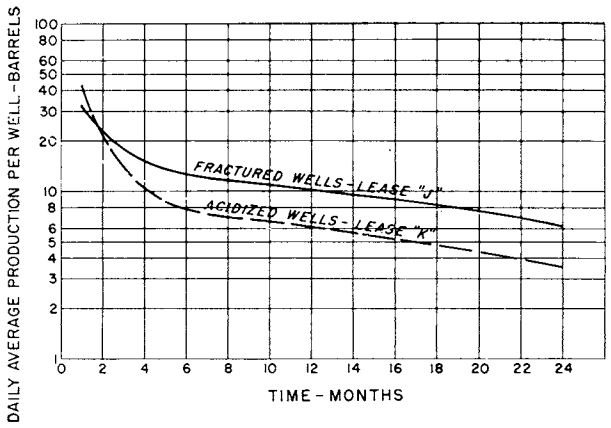

Fig. 5—Production decline curves, fracturing vs acidizing.

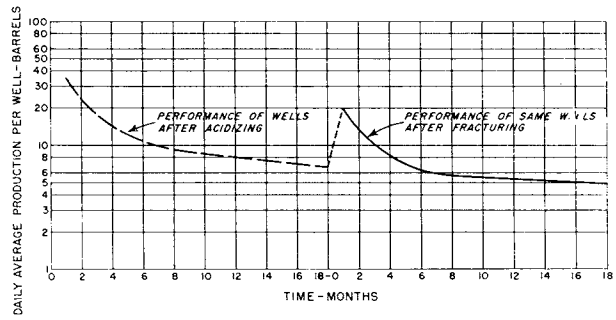

Fig. 6—Production decline curves, fracturing vs acidizing, Lease L.

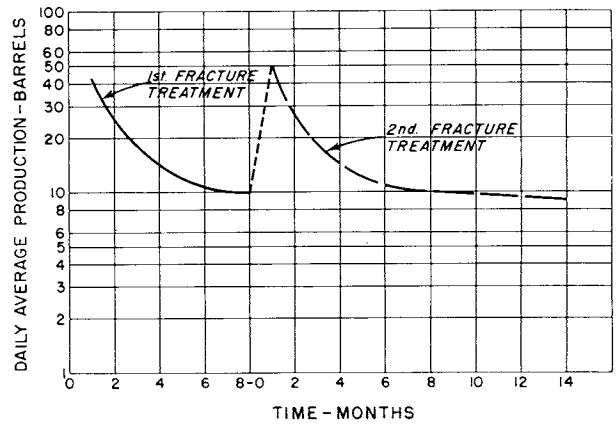

Fig. 7—Production decline curves, Lease M.

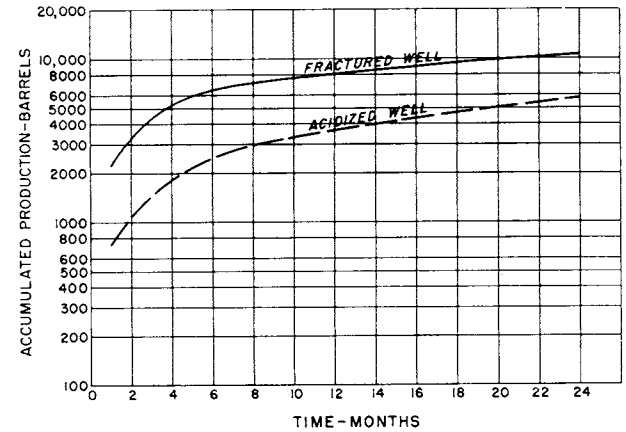

Fig. 8—Accumulated production comparison, fracturing vs acidizing, Lease L.

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Decline Period	Daily Average Production Per Well: After Acidizing and Before Fracturing	After Fracturing
1 Month	35.0	20.1
6 Months	10.8	6.4
12 Months	8.0	5.4
18 Months	6.6	4.9

This lease responded favorably to acid treatments and the above results would indicate that fracturing of old wells in these areas does not increase the production as much as in the extremely tight Chalk area. The lower production rates after fracturing might also indicate that the saturation in the affected area was less than in a new well because the production on newly fractured wells on this lease is considerably higher as will be shown on the accumulative productive curve. However, the wells compared had declined to an average of 4.5 B/D before fracturing; and as shown by the decline curves, sufficient oil has been recovered since the recompletion to justify the expense.

Production from Refractured Well

The decline curves shown in Fig. 7 compares one newly fractured well to the same well which was refractured on Lease M located near the center of the Chalk producing area in Section 32, T21N, R16W. This well was drilled in July, 1953, and was completed by setting casing on top of the lower Chalk zone. The well was fractured by treating the open hole in the lower zone with 8,000 lb of sand and 130 bbl of oil. The sand concentration was 1.7 lb/gal and the average injection pressure was 1,500 psig. The injection rate was 6 bbl/min. The well was retreated in April, 1954, in the same zone with 20,000 lb of sand and 276 bbl of oil. The sand concentration was 1.9 lb/gal and the average injection pressure was 2,500 psig with a final pressure of 450 psig. The average injection rate was 4.5 bbl/min. The daily average production for the well after each treatment is as follows.

Decline Period	Daily Average Production: First Fracture	Second Fracture
1 Month	42.0	50.1
6 Months	10.8	10.9
8 Months	10.0	10.4
14 Months	—	9.0

The accumulated production for the 14-months' period after the second fracture treatment was approximately 5,820 bbl of oil. Assuming the well would have declined at a constant rate of 10 B/D after the first treatment, an accumulated production of 4,200 bbl would occur for this 14-months' period. The difference of 1,620 bbl is considered the minimum additional recovery from the re-treatment and the future decline may be retarded as a result of the larger treatment.

Newly-Fractured vs Newly Acidized Well

The accumulated production curves shown in Fig. 8 compare a newly fractured well with a newly acidized well on Lease L which has been previously described. The fractured well compared was drilled in Oct., 1953, and was completed by setting casing on top of the bottom Chalk zone. The well was fractured by selectively treating the three zones with a total of 31,000 lb of sand and 450 bbl of oil. The sand concentration was 2 lb/gal and the average injection pressure was 2,200 psig with a final pressure of 500 psig. The average injection rate was 5.2 bbl/min. The acidized well compared was drilled in Oct., 1951, and was completed by setting casing on top of the middle zone. The well was acidized by treating the lower and middle zones in the open hole with 5,000 gal of regular 15 per cent HCl acid. The average injection pressure was 350 psig. The accumulated production for these wells is as follows.

Period	Accumulated Production: Fractured Well	Acidized Well
1 Month	2204	712
6 Months	6418	2466
12 Months	8106	3674
18 Months	9516	4742
24 Months	10630	5775

The wells selected for this comparison were considered as average producers on the lease for an acid or fracture completion, and the results show that a fractured well will produce considerably more oil than an acidized well even where acid results were exceptionally good. The percentage increase in recovery for the fractured wells will be even greater in the tight Chalk producing area. As shown in Fig. 2, wells are being completed in areas where acid completions would not result in a commercial well.

Conclusions

1. New producing areas in the Annona Chalk reservoir have become an economic source for oil production as a direct result of hydraulic fracturing operations.
2. Low drilling, completion, and production costs are essential to profitable operations of these stripper wells and they have been achieved in the field.
3. The recovery of oil in place is still considered small and the reservoir offers an excellent proving ground for experimental testing of future completion techniques and production methods.

Acknowledgments

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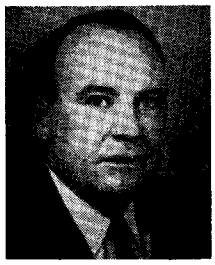

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