Hydraulic Fracture Treatment Evaluation Shafter Lake San Andres Unit Shafter Lake (San Andres) Field

JOHN E. SMITH
Mobil Oil Corporation

INTRODUCTION

The Shafter Lake San Andres Unit was formed on July 1, 1967, and water injection was initiated in August, 1968. Prior to the start of water injection, an extensive stimulation program was undertaken to increase current production from the unit wells and to prepare them for flood response. Since the initiation of the stimulation program in September, 1967, a total of 40 hydraulic fracturing treatments have been performed on 38 wells using lease oil, refined oil, and salt water as fracturing fluids. Of the 40 fracturing treatments that were conducted, lease oil was used on five treatments, refined oil was used on 13 treatments, and salt water was used on 22 treatments. The investigation described in this paper was undertaken to determine the relative effectiveness of oil-base and water-base fracturing fluids used in the 40 fracturing treatments and to evaluate the overall results of the entire fracturing program. To accomplish the above objectives, it was necessary to evaluate the design criteria and treatment procedures employed in the fracturing treatments and to describe the prefractured quality of the wells that were fractured. A detailed investigation of each fracturing treatment and two computer programs, one for designing hydraulic fracture treatments and one for determining well reconditioning economics, were used in attaining the objectives.

HISTORY

The Shafter Lake (San Andres) Field is located in central Andrews County, just northwest of the town of Andrews, Texas. The discovery well, Deep Rock Oil Company's C. E. Ogden No. 1, was completed on December 12, 1929. The well had an initial pumping potential of 200 BOPD and 0 BWPD and is currently producing at the rate of 17 BOPD and 5 BWPD. Development of the field was slow until 1953 with the completion of only 21 wells up to that time. The bulk of the development was from 1953 through 1956. By 1959, there was a total of 338 wells in the field. The field is fully defined by dry holes and marginal edge well completions. Peak primary producing rate was reached in 1955 when 5135 BOPD were produced.

The Shafter Lake San Andres Unit was formed on July 1, 1967. In February, 1968, water injection was initiated in 26 wells in the north end of the unit, and in August, 1968, the remainder of the unit was put under flood. The unit presently has 177 producing wells, 68 water injection wells, and 29 shut-in wells. Refer to Fig. 1 for the current status of the unit. Producing rate of the unit is now approximately 3100 BOPD, and a projected peak secondary producing rate of approximately 6200 BOPD is expected to be reached in 1972.

Prior to the start of water injection, an extensive stimulation program was undertaken to increase current production from the unit wells and to prepare them for flood response. Since the initiation of the stimulation program in September, 1967, a total of 40 hydraulic fracturing treatments have been performed on 38 wells using lease oil (33.5° API), refined oil (20° API), and salt water (9.0 lb/gal.) as fracturing fluids. Of the 40 fracturing treatments that were conducted, lease oil was used on five treatments, refined oil was used on 13 treatments, and salt water was used on 22 treatments. The location of each well that was fractured is shown in Fig. 1.

Before beginning the Shafter Lake San Andres Unit fracturing program, a search of the well files of all unit wells, as well as a search of the stimulation files of the major service companies, was conducted to determine what type of base fluid was used in the past fracturing treatments performed in the subject field. This investigation yielded the results presented in Table 1.

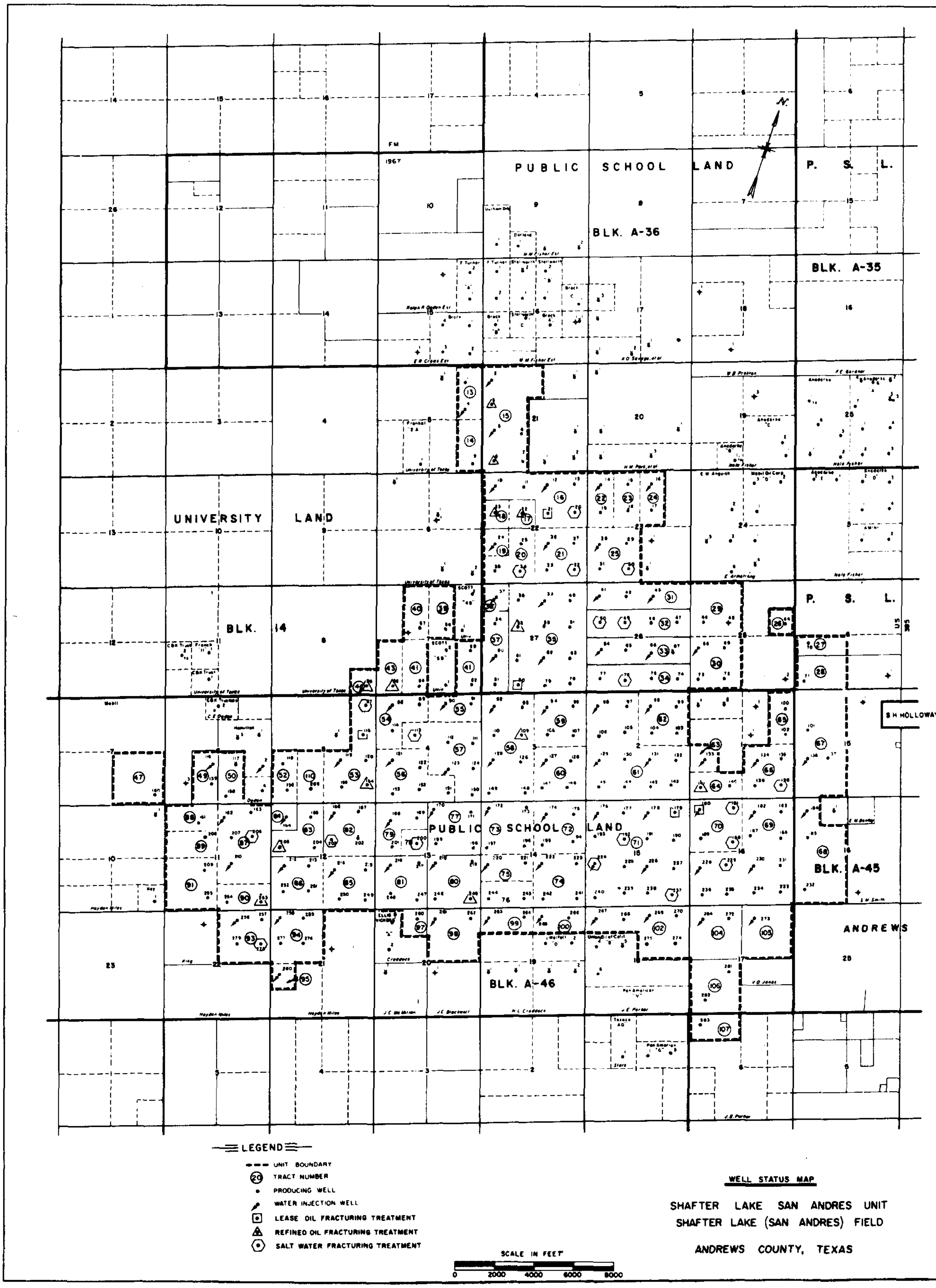
PUBLIC SCHOOL LAND
BLK. A-36
BLK. A-35
P. S. L.
UNIVERSITY LAND
BLK. 14
PUBLIC SCHOOL LAND
BLK. A-45
BLK. A-46
ANDREWS
S H HOLLOWAY
LEGEND
UNIT BOUNDARY
TRACT NUMBER
PRODUCING WELL
WATER INJECTION WELL
LEASE OIL FRACTURING TREATMENT
REFINED OIL FRACTURING TREATMENT
SALT WATER FRACTURING TREATMENT
SCALE IN FEET
0 2000 4000 6000 8000
WELL STATUS MAP
SHAFTER LAKE SAN ANDRES UNIT
SHAFTER LAKE (SAN ANDRES) FIELD
ANDREWS COUNTY, TEXAS

FIGURE 1

Examination of Table 1 shows that from 1956 through 1964 practically all the fracturing treatments were performed utilizing oil-base fluids. In 1965, oil-base and water-base fracturing treatments were approximately equal, and in 1967, water-base fluids were employed on 100 per cent of the fracturing treatments.

TABLE 1

TREND IN FRACTURING BASE FLUIDS

Year	Percentage of Treatments Performed: Lease Oil	Refined Oil	Salt Water
1956	86	0	14
1957	20	80	0
1958	0	100	0
1959	80	0	20
1960	100	0	0
1961	100	0	0
1962	100	0	0
1963	100	0	0
1964	100	0	0
1965	42	16	42
1966	29	0	71
1967	0	0	100
Average	60	12	28

GEOLOGY AND RESERVOIR DATA

The Shafter Lake (San Andres) Field is located on the Central Basin Platform of the Permian Basin. Hydrocarbon accumulation is due primarily to convex folding creating a stratigraphic trap, with updip and lateral termination of oil and gas deposits due to a decrease in porosity and permeability and downdip increase in water production. Local structure takes the form of a gently dipping monocline, trending north and south with a dip of approximately 75 ft/mile. Production is from the Grayburg and San Andres formations, both of Permian age. The Grayburg formation consists of sandy dolomite and shaley sand with some anhydrite inclusions. The San Andres formation is a massive dolomite with anhydrite inclusions and occasional sand and shale stringers. The average producing depths of the Grayburg and San Andres formations are 4400 ft and 4550 ft, respectively, and the combined average gross producing interval of the two formations is approximately 300 ft.

From a statistical analysis of cores from 19 wells in the unit area with the Grayburg and San Andres intervals combined, the average porosity of all samples having greater than 0.1 md permeability was 6.5 per cent. The average horizontal permeability and average interstitial water saturation of the same samples was 5.0 md and 25 per cent, respectively.

Table 2 contains data obtained from a PVT analysis report[1] on a fluid sample from the Shafter Lake San Andres Unit Well 95. The PVT analysis was conducted under reservoir temperature conditions of 98° F.

FRACTURE TREATMENT DESIGN

Design of the 40 fracturing treatments analyzed in this paper was performed on Mobil's Midland Division IBM 1130 computer employing Program No. M7000 entitled, "Design of Hydraulic Fracture Treatments".[2] This program is based on fracturing concepts that have been previously described in the literature.[3,4]

Initially, a fracture treatment design was performed on each well that was fractured; however, it soon became apparent that a comprehensive fracture treatment design study would provide adequate design criteria that could be applied to the remainder of the wells to be fractured. This study was conducted, and the results are presented in Table 3.

A plot of fracture height vs fracturing fluid volume using the data contained in Table 3 is presented in Fig. 2. Where reasonably accurate values of fracture height can be obtained, Fig. 2 can be utilized to size future fracturing treatments in the subject unit.

Fracture treatment computer designs for a typical Shafter Lake San Andres Unit well using lease oil, refined oil, and salt water as

TABLE 2
PVT ANALYSIS DATA

	Initial Conditions	Start of Flood Conditions	Current Conditions
Bottom Hole Pressure, Psig	1,865	550	750
Bubble Point Pressure, Psig	1,865	-	-
Solution Gas-Oil Ratio, Ft^3/Bbl	500	225	270
Formation Volume Factor, Res Bbl/STB	1.25	1.14	1.16
Oil Viscosity at Bubble Point, Cp	1.34	2.50	2.22
Oil Gravity, ° API	33.5	33.5	33.5

TABLE 3
FRACTURE TREATMENT DESIGN RESULTS

	Lease Oil	Refined Oil	Salt Water
Fracturing Fluid Volume (Gals/Ft)			
100 Ft Fracture Height	90	70	90
300 Ft Fracture Height	140	80	140
500 Ft Fracture Height	160	80	160
Sand Quantity (Lbs/Gal)	1.5	3.0	1.5
Injection Rate (Bbls/Min)	40	25	50
Fluid Loss Additive (25 Lbs/1,000 Gals)	25	25	25
Lease Oil - Adomite Mark II			
Refined Oil - Adomite Mark II			
Salt Water - Adomite Aqua			
Gelling Agent (20 Lbs/1,000 Gals)	0	0	20
Salt Water - Guar Gum			
Non-emulsifying Agent (2 Gals/1,000 Gals)	0	0	2
Salt Water - Sufatron 61			

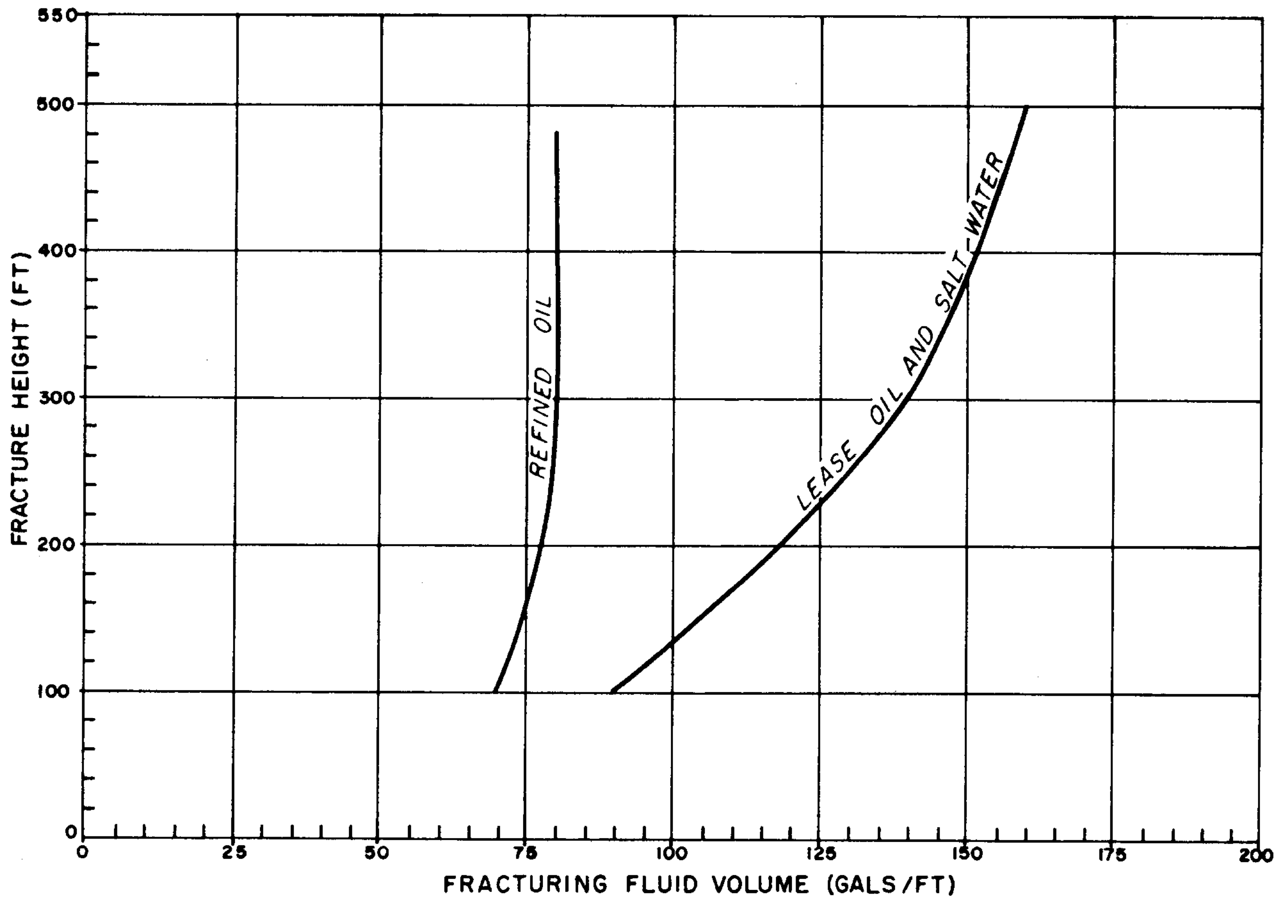

FIGURE 2

EFFECT OF FRACTURE HEIGHT ON FRACTURING FLUID VOLUME

fracturing fluids were performed, and the design results are summarized in Table 4.

Fracture treatment costs for each type of fracturing fluid investigated in the typical well fracture treatment designs are presented in Table 5. These costs were prepared using published service company price lists and are for a well completed as follows:

1. 5½ in. production casing
2. Open-hole completion or cased-hole completion having high perforation density and/ or enlarged perforations

An economic comparison of typical well fracture treatment cost per 1000 ft^2 of fracture area for each type of fracturing fluid investigated is presented in Table 5. Examination of this data shows that rated on fracture treatment cost per 1000 ft^2 of fracture area, refined oil ranked first, lease oil ranked second, and salt water ranked third.

FRACTURE TREATMENT RESULTS

Economic calculations used in the analysis of the 40 fracturing treatments were performed on Mobil's Midland Division IBM 1130 computer employing Program No. M7006 entitled, "Well Reconditioning Review".[5] This program is based on concepts that had been previously developed and used in earlier hand calculated versions of Mobil well reconditioning reviews.[6] Program No. M7006 is normally used to prepare Mobil's Midland Division quarterly well reconditioning reviews; therefore, it was necessary to alter the program somewhat for use in this paper. The changes were not too difficult, and the program provided excellent answers. An output data summary of the workover results for each type of fracturing fluid and for a combination of the three types of fracturing fluids is presented in Table 6.

TABLE 4

TYPICAL WELL FRACTURE TREATMENT DESIGN SUMMARY

	Lease Oil	Refined Oil	Salt Water
Fracture Height (Ft)	400	400	400
Fracture Penetration (%)	32	32	32
Fracture Area (Ft^2)	169,000	169,000	169,000
Fracturing Fluid Volume (Gals)	60,000	31,000	62,000
Sand Quantity (Lbs)	95,000	95,000	95,000
Injection Rate (Bbls/Min)	40	25	50
Productivity Ratio (Dimensionless)	1.9	1.9	1.9

Workover result classifications (successful and unsuccessful) found in Table 6 were based on profit indicators. Workovers were classified as successful when the profit indicators equalled or exceeded those normally required for capital investments with analysis considering workover costs as an investment. Federal income tax was included in the calculations at a rate of 48 per cent.

Examination of Table 6 shows that rated in the order of economic return, wells fractured with lease oil ranked first, wells fractured with refined oil ranked second, and wells fractured with salt water ranked third.

Individual well reserves used in the economic calculations were obtained from decline curve analysis employing decline curve analysis methods proposed by Arps[7] and Schoemaker.[8] Each well was assigned only those reserves which could be attributed directly to the fracturing treatment performed on the well. No secondary reserves were assigned to any well.

Net oil value of $1.90/bbl was used in the economic calculations. This number was calculated from the following data which were obtained from Mobil's Lease Income and Expense Statement Report.[9]

1.	Net working interest—	0.875
2.	Gross Oil Value—	$2.78/bbl
3.	State and local taxes—	$0.20/bbl
4.	Operating expenses—	$0.33/bbl

Examination of Table 7 reveals the following types of workover costs for each well:

1. Estimated workover cost
2. Actual workover cost
3. Adjusted workover cost

The estimated workover cost is the cost that was estimated prior to performing the workover. The actual workover cost is the cost that was actually required to perform the workover. The adjusted workover cost is the actual workover cost less the cost of any unusual troubles encountered such as casing leaks, fishing jobs, etc. In an effort to be equitable in the comparison of the fracturing fluids, the adjusted workover cost was used in the economic calculations.

Examination of the well files of the 38 wells that were fractured provided all the data that are usually associated with any fracturing treatment (refer to Tables 7, 8, 9); however, the following items were of unusual interest and warrant further discussion:

1. Breakdown acid use
2. Borehole televiewer results
3. Load fluid recovery time
4. Pump pulling frequency
5. Selectivity agent performance
6. Zone coverage

No definite conclusions can be made concerning the breakdown acid that was used in all but four of the 40 fracturing treatments; however, it is the belief of this writer that the use

TABLE 5
TYPICAL WELL FRACTURE TREATMENT COSTS

	Lease Oil	Refined Oil	Salt Water
Fracturing Fluid	$ 0	$ 930	$ 372
Lease Oil - 60,000 Gals - No Charge			
Refined Oil - 31,000 Gals @ $0.03/Gal			
Salt Water - 62,000 Gals @ $0.006/Gal			
Frac Tanks @ $125 Each	500	375	500
Lease Oil - 4 Tanks			
Refined Oil - 3 Tanks			
Salt Water - 4 Tanks			
Frac Sand - 95,000 Lbs @ $1.91/CWT	1,815	1,815	1,815
Frac Sand Mileage Charge - 1,045 Ton-Miles @ $0.021/Ton-Mile	240	240	240
Hydraulic Horsepower @ $1.10/HHP	2,372	1,280	1,887
Lease Oil - 2,156 HHP			
Refined Oil - 1,164 HHP			
Salt Water - 1,715 HHP			
Proportioners			
Lease Oil - 40 Bbls/Min	365	272	411
Refined Oil - 25 Bbls/Min			
Salt Water - 50 Bbls/Min			
Blocking Agent	75	75	138
Lease Oil - 2,500 Lbs Rock Salt @ $0.03/Lb			
Refined Oil - 2,500 Lbs Rock Salt @ $0.03/Lb			
Salt Water - 2,500 Lbs Rock Salt @ $0.03/Lb			
Salt Water - 6,250 Lbs Pink Salt @ $0.01/Lb			
Mixing Trucks @ $100 Each	100	100	100
Fluid Loss Additive	1,005	519	853
Lease Oil - 1,500 Lbs @ $0.67/Lb			
Refined Oil - 775 Lbs @ $0.67/Lb			
Salt Water - 1,550 Lbs @ $0.55/Lb			
Gelling Additive	0	0	1,240
Salt Water - 1,240 Lbs @ $1.00/Lb			
Non-emulsifying Additive	0	0	403
Salt Water - 124 Gals @ $3.25/Gal			
Breakdown Acid - 1,000 Gals @ $0.27/Gal	270	270	270
Acid Pump Trucks @ $199 Each	199	199	199
Total	$ 6,941	$ 6,075	$ 8,428
Fracture Area (Ft^2)	169,000	169,000	169,000
Cost Per 1,000 Ft^2 of Fracture Area ($/1,000 Ft^2)	41	36	50

TABLE 6

WORKOVER ECONOMICS COMPUTER OUTPUT SUMMARY

	Lease Oil	Refined Oil	Salt Water	Total
Number of Workovers				
Successful	5	10	13	28
Unsuccessful	0	3	7	10
Total	5	13	20	38
Success Ratio, %	100	77	65	74
Production Before Workovers, Bbls/Cal Day	36	76	120	232
Production After Workovers, Bbls/Cal Day	319	411	775	1,505
Production Increase Attributed to Workovers, Bbls/Cal Day	283	335	655	1,273
Reserves Attributed To Workovers, Bbls	106,000	233,000	309,000	648,000
Net Income Attributed To Workovers, $	201,400	442,700	587,100	1,231,202
Net Income Per Barrel, $/Bbl	1.90	1.90	1.90	1.90
Cost of Workovers, $	48,330	113,553	256,378	418,261
Workover Cost Variance, $	5,270	4,947	-13,378	-3,161
Workover Cost Variance, %	9.83	4.17	-5.50	-0.76
Final Financial Status of Workovers, $	116,333	250,153	251,349	617,835
Annual Rate of Return, %	100	93	100	100
Net Profit Per Dollar Invested, $/$	2.41	2.20	0.98	1.47
Payout, Yrs	0.24	0.48	0.56	0.47
Future Life, Yrs	2	4	3	3

of acid was a good stimulation procedure. On any fracturing treatment, breakdown acid cleans up the perforations and/or open hole, and if the acid penetration extends beyond the loop stress area around the wellbore (approximately 2.5 wellbore diameters), breakdown pressures are reduced.[10]

The borehole televiewer was run on two (Well Nos. 180 and 192) of the 38 wells that were fractured. The televiewer was run on both of the wells for the purpose of casing inspection. Well No. 180 had bad casing and extremely large perforations. Most old perforations had diameters of approximately two in., and two perforations were found with diameters of six to eight in. In addition, partially collapsed casing was found at 4563 ft. Well No. 192 also had bad casing. Pitting and pin holes were found at 530 ft, 1163 ft, and 1170 ft, and a 1 to 1½ in. diameter hole was located at 1210 ft.

Examination of Table 7 shows the average time required to begin recovering new oil was 38 days for lease oil fracturing treatments, 36 days for refined oil fracturing treatments, and 7 days for salt water fracturing treatments. In summary oil-base fracturing treatments required approximately 30 days longer to recover load fluid than did water-base fracturing treatments. It should be pointed out that any increased load-fluid recovery time does in actuality affect economics in that income is delayed and lifting cost expenses are incurred during the additional load fluid recovery time; however, the increased load-fluid recovery time is usually so small that the effect on economics can be neglected. This certainly was the case for the fracturing treatments analyzed in this paper, since the additional load recovery time was only 30 days.

Examination of Table 7 shows that the number of pump pulling operations was zero for the five lease oil fracturing treatments, eight for the 13 refined oil fracturing treatments, and one for the 22 salt water fracturing treatments. Rated in the order of the smallest number of pump pulling operations, lease oil ranked first, salt water ranked second, and refined oil ranked third.

Pump pulling operations immediately following a fracturing treatment can be attributed primarily to frac sand being transported back into the wellbore by the fracturing fluid. In general, high viscosity fracturing fluids will transport more frac sand back into the wellbore than will low viscosity fracturing fluids. Pump pulling frequency data in Table 7 bears out this phenomenon in that refined oil (107.0 cp @ 98° F) fracturing treatments had more pump pulling operations than the lease oil (5.6 cp @ 98° F) and salt water (5.9 cp gelled and 1.0 cp ungelled @ 98° F) fracturing treatments combined.

Frac evaluation logs were run on 37 of the 38 wells that were fractured. The large number of logs in one concentrated area provided an excellent opportunity to study zone coverage and fracture height. In general, zone coverage was fairly good, and predicted fracture height barriers contained the fractures reasonably well. Detailed data obtained from each frac evaluation log are presented in Table 8.

The following four types of selectivity agents were used in the 40 fracturing treatments analyzed in this paper:

1. Rubber-covered nylon ball sealers
2. Rock salt
3. Naphthalene
4. Unibeads

In cased-hole completions having low perforation density and average size perforations, rubber-covered nylon ball sealers performed superiorly to granular blocking agents for selectivity. In open-hole completions and cased-hole completions having high perforation density and/or enlarged perforations, rock salt was more effective than naphthalene or Unibeads for selectivity. Where rock salt was used for selectivity in conjunction with a water-base fracturing fluid, it was found that each stage of the rock salt had to be carried in a solution of saturated salt water to minimize dissolving of the rock salt. Detailed selectivity data for each of the 40 fracturing treatments is presented in Table 9.

To fully analyze the results of the fracture treatments investigated in this paper, it was necessary to describe the prefracture quality of the 38 wells that were fractured. Criteria used in determining the prefractured quality of each well were primary performance and damage ratio. Damage ratios were determined by dividing theoretical productivity ratios into actual productivity ratios, and primary performance ratings were based on the following standards:

Above average—over 100,000 bbl cumulative primary oil production.

TABLE 7

HYDRAULIC FRACTURING TREATMENT DATA

Well No.	Workover Completion Date	Acid Volume (Gals)	Frac Fluid Type	Frac Fluid Quantity (Gals)	Sand[1] Quantity (Lbs)	Fluid Loss Type[2]	Fluid Loss Quantity (Lbs/M Gals)	Gelling Agent Type[3]	Gelling Agent Quantity (Lbs/M Gals)	Non-emulsifying Agent Type	Non-emulsifying Agent Quantity (Gals/M Gals)	Injection Rate (Bbls/Min)	Time To New Oil (Days)	Number Pump Pulling Jobs	Estimated Workover Cost ($)	Actual Workover Cost ($)	Adjusted Workover Cost ($)	Primary Performance Well Rating[4]	Remarks
80	12-11-67	0	Lease Oil	68,000	102,000	AM	25	None	0	None	0	42.5	29	0	11,200	9,089	9,089	A	
179	12-5-67	500	Lease Oil	55,000	87,000	AM	25	None	0	None	0	39.6	51	0	11,900	8,741	8,741	A	
180	10-5-67	1,000	Lease Oil	55,000	82,500	AM	25	None	0	None	0	39.7	31	0	9,500	9,500	9,500	B	Televiewer log indicated bad casing and extremely large perforations (2"-8" in diameter).
21	4-10-68	300	Lease Oil	75,000	112,500	AM	25	None	0	None	0	46.0	57	0	10,000	13,627	10,000	C	Fishing operations.
115	4-2-68	1,000	Lease Oil	75,000	112,500	AM	25	None	0	None	0	32.0	21	0	11,000	13,627	11,000	C	Casing leak repair.
22	10-16-67	1,000	Refined Oil	40,000	120,000	AM	25	None	0	None	0	32.0	35	2	8,600	13,519	8,600	B	CO operations. Junk in the hole.
53	12-7-67	0	Refined Oil	37,000	111,000	AM	25	None	0	None	0	33.5	19	0	9,600	8,023	8,023	A	
85	2-27-68	1,000	Refined Oil	36,000	108,000	AM	25	None	0	None	0	28.0	84	0	13,800	14,041	14,041	C	CO 80' and DD 17' with air.
141	4-8-68	1,000	Refined Oil	30,000	90,000	AM	25	None	0	None	0	15.5	27	0	8,700	11,827	8,700	A	Casing leak repair
3	6-28-69	1,500	Refined Oil	10,000	30,000	AM	25	None	0	None	0	13.9	70	0	5,400	10,843	5,400	C	No perforations. Screened out with 2,000 gals and 6,000 lbs in the formation. Rate - 8 to 0 BPM. Reperforated.
8	1-9-69	1,000	Refined Oil	30,000	90,000	AM	25	None	0	None	0	25.6	17	0	8,700	7,555	7,555	C	Refraced with 8,000 gals and 24,000 lbs. Rate - 15.4 BPM.
23	10-17-69	300	Refined Oil	24,400	72,000	AM	25	None	0	None	0	18.4	33	4	7,700	10,066	7,700	C	No perforations. Screened out with 4,400 gals and 13,000 lbs in the formation. Rate - 24 to 0 BPM. Reperforated. Refraced with 20,000 gals and 59,000 lbs. Rate - 17 BPM.
86	1-8-69	1,000	Refined Oil	35,000	105,000	AM	25	None	0	None	0	32.5	27	1	9,600	11,000	9,600	C	Fishing operations.
109	1-15-69	1,000	Refined Oil	30,000	90,000	AM	25	None	0	None	0	25.0	35	0	8,800	8,754	8,754	A	
154	1-15-69	1,000	Refined Oil	35,000	105,000	AM	25	None	0	None	0	25.0	22	0	9,600	8,275	8,275	C	
205	1-15-69	1,000	Refined Oil	35,000	105,000	AM	25	None	0	None	0	31.0	20	0	9,500	9,597	9,597	C	
245	1-3-69	1,000	Refined Oil	30,000	90,000	AM	25	None	0	None	0	32.0	30	0	8,400	8,295	8,295	B	
253	2-4-69	1,000	Refined Oil	40,000	120,000	AM	25	None	0	None	0	21.0	49	1	10,100	9,013	9,013	A	
20	11-18-67	1,000	Salt Water	75,000	112,500	AA	28	GG	23	None	0	44.0	10	0	13,500	24,800	13,500	C	Casing leak repair.
32	11-1-67	1,000	Salt Water	60,000	90,000	AA	25	GG	20	Surfatron 61	2	56.9	6	1	9,000	10,556	10,556	B	
49	9-28-67	1,000	Salt Water	65,000	97,500	None	0	GG	42	None	0	39.0	7	0	10,000	10,728	10,728	B	
76	10-23-67	1,000	Salt Water	65,000	97,500	SF	24	GG	25	None	0	47.0	9	0	14,500	15,524	14,000	A	Casing leak repair. DD 24' with water.
87	11-25-67	1,000	Salt Water	75,000	112,500	AA	25	GG	20	Surfatron 61	2	54.0	10	0	13,300	13,300	13,300	C	
113	11-18-67	0	Salt Water	30,000	45,000	AA	38	GG	27	None	0	50.0	10	0	13,000	11,834	11,834	C	Fishing operations.
113	11-18-67	1,000	Salt Water	30,000	45,000	AA	35	GG	25	None	0	30.0	-	-	-	-	-	-	
138	11-7-67	1,000	Salt Water	65,000	97,500	AA	30	GG	20	Surfatron 61	2	53.0	2	0	10,000	12,338	12,338	A	
181	11-29-67	500	Salt Water	55,000	82,500	AA	25	GG	20	Surfatron 61	2	52.4	2	0	12,200	8,487	8,487	B	
188	11-30-67	500	Salt Water	55,000	82,500	AA	25	GG	20	Surfatron 61	2	51.5	4	0	12,200	10,051	10,051	B	
192	10-23-67	1,000	Salt Water	50,000	75,000	SF	23	GG	24	None	0	48.0	7	0	11,500	25,904	13,804	A	Televiewer log indicated bad casing. Several leaks located. Casing leak repair. DD 28' with water.
200	11-23-67	0	Salt Water	60,000	90,000	AA	33	GG	20	None	0	50.0	2	0	9,500	9,500	9,500	C	
203	11-27-67	1,000	Salt Water	75,000	112,000	AA	25	GG	20	Surfatron 61	2	39.5	2	0	12,000	15,716	13,216	B	Casing leak repair.
224	9-23-67	1,000	Salt Water	45,000	67,500	SF	20	GG	20	None		68.0	5	0	8,500	8,500	8,500	A	
229	11-16-67	1,000	Salt Water	55,000	82,500	AA	25	GG	20	Surfatron 61	2	52.1	11	0	11,100	10,714	10,714	C	Casing leak repair.
278	11-16-67	1,000	Salt Water	78,000	117,000	AA	25	GG	20	Surfatron 61	2	54.0	5	0	12,600	12,600	12,600	B	
30	1-7-68	500	Salt Water	55,000	82,500	AA	35	GG	23	None	0	54.0	∞	0	12,800	16,037	16,037	C	
34	1-8-68	3,000	Salt Water	65,000	97,500	AA	25	GG	20	None	0	55.2	7	0	15,600	19,090	19,090	B	
206	6-5-68	1,000	Salt Water	45,000	67,000	AA	26	GG & FR	20 & 0.7	Surfatron 61	2	43.0	8	0	15,500	16,157	16,157	A	
206	6-5-68	1,000	Salt Water	20,000	30,000	AA	25	GG & FR	20 & 1.5	Surfatron 61	2	56.0	-	-	-	-	-	-	
50	12-8-69	1,000	Salt Water	60,000	120,000	AA	25	GG	20	Surfatron 61	2	49.0	10	0	12,500	12,500	12,500	B	
237	1-5-69	1,000	Salt Water	60,000	90,000	AA	25	GG & FR	22 & 0.4	Surfatron 61	2	42.0	7	0	8,700	19,466	19,466	A	

LEGEND:

1 All Fracturing Sand Was 20-40 Mesh Ottawa
2 AM - Adomite Mark II; AA - Adomite Aqua; SF - Silica Flour
3 GG - Guar Gum; FR - Friction Reducer
4 A - Above Average - Cumulative Primary Oil Production = Over 100,000 Bbls
B - Average - Cumulative Primary Oil Production = 50,000 to 100,000 Bbls
C - Below Average - Cumulative Primary Oil Production = Below 50,000 Bbls

TABLE 8
FRAC EVALUATION LOG DATA

Well No.	Workover Completion Date	Frac Fluid Type	Completion Type	Completion Interval	Frac Evaluation Log	Remarks
80	12-11-67	Lease Oil	Perfs	4,236'-4,526'-290' OA - 600 Holes	Yes	Top of frac @ 4,150'. Good volume from 4,150' to 4,280'. Some frac below 4,534'. Did not log below fractured interval.
179	12-5-67	Lease Oil	Perfs	4,326'-4,594'-268' OA - 464 Holes	Yes	Top of frac @ 4,304'. Good volume from 4,304' to 4,596'. All perfs took frac. Some frac below 4,589'. Did not log below fractured interval.
180	10-5-67	Lease Oil	Perfs	4,317'-4,620'-303' OA - 912 Holes	Yes	Top of frac @ 4,283'. Good volume from 4,283' to 4,351'. Good volume from 4,389' to 4,471'. Good volume from 4,529' to below logging T.D. (4,605'). *Good volume out bottom. Did not log below fractured interval.*
21	4-10-68	Lease Oil	Perfs	4,340'-4,590'-250' OA - 480 Holes	Yes	Top of frac @ 4,280'. Small volume from 4,280' to 4,400'. Good volume from 4,435' to below logging T.D. (4,567'). Did not log below fractured interval.
115	4-2-68	Lease Oil	Perfs	4,174'-4,515'-341' OA - 252 Holes	Yes	Top of frac @ 4,210'. Good volume from 4,210' to 4,484'. Did not log below fractured interval.
22	10-16-67	Refined Oil	Perfs	4,318'-4,592'-274' OA - 517 Holes	Yes	Top of frac @ 4,250'. Good volume from 4,518' to below logging T.D. (4,587'). All perfs appear to be communicated. Did not log below fractured interval.
53	12-7-67	Refined Oil	Perfs Open Hole	4,230'-4,586'-356' OA - 896 Holes 4,597'-4,602'- 5'	Yes	Top of frac @ 4,160'. Good volume from 4,160' to below logging T.D. (4,574'). Did not log below fractured interval.
85	2-27-68	Refined Oil	Perfs Open Hole	4,080'-4,501'-421' OA - 126 Holes 4,512'-4,529'-17'	Yes	Top of frac @ 4,100'. Small volume from 4,100' to 4,244'. Good volume from 4,244' to 4,460'. All perfs took frac. Possible small volume below logging T.D. (4,494').
141	4-8-68	Refined Oil	Perfs	4,334'-4,618'-284' OA - 472 Holes	Yes	Top of frac @ 4,280'. Good volume from 4,280' to 4,464'. Small volume from 4,464' to below logging T.D. (4,593'). All perfs took frac. Did not log below fractured interval.
3	6-28-69	Refined Oil	Perfs	4,322'-4,386'- 64' OA - 13 Holes	Yes	Top of frac @ 4,252'. Good volume from 4,252' to below logging T.D. (4,398'). All perfs took frac. Did not log below fractured interval.
8	1-9-69	Refined Oil	Perfs	4,341'-4,586'-245' OA - 418 Holes	Yes	Top of frac @ 4,340'. Good volume from 4,340' to 4,520'. Small volume from 4,520' to below logging T.D. (4,583'). Did not log below fractured interval.
23	10-17-69	Refined Oil	Perfs	4,302'-4,570'-268' OA - 560 Holes	Yes	Top of frac @ 4,334'. Good volume from 4,334' to 4,407'. Small volume from 4,407' to 4,453'. Good volume from 4,453' to below logging T.D. (4,489'). Did not log below fractured interval.
86	1-8-69	Refined Oil	Perfs	4,170'-4,498'-328' OA - 650 Holes	Yes	Top of frac @ 4,168'. Good volume from 4,168' to 4,400'. Small volume from 4,400' to 4,505'. All perfs took frac.
109	1-15-69	Refined Oil	Perfs	4,284'-4,523'-239' OA - ? Holes	Yes	Top of frac @ 4,045'. Good volume from 4,045' to 4,323'. Good volume from 4,349' to 4,447'. Some frac may possibly have gone below logging T.D. (4,470').
154	1-15-69	Refined Oil	Perfs	4,175'-4,501'-326' OA - 368 Holes	Yes	Top of frac @ 4,168'. Good volume from 4,220' to below logging T.D. (4,448'). Did not log below fractured interval.
205	1-15-69	Refined Oil	Perfs	4,177'-4,508'-331' OA - 300 Holes	Yes	Top of frac @ 4,274'. Good volume from 4,376' to 4,470'.
245	1-3-69	Refined Oil	Open Hole	4,360'-4,574'-214'	Yes	Top of frac @ 4,312'. Good volume from 4,456' to 4,556'. Some frac below logging T.D. (4,556'). Did not log below fractured interval.
253	2-4-69	Refined Oil	Perfs	4,142'-4,490'-348' OA - ? Holes	Yes	Top of frac @ 4,087'. Good volume from 4,087' to 4,300'. Small volume from 4,300' to below logging T.D. (4,483'). Did not log below fractured interval.
20	11-18-67	Salt Water	Perfs	4,332'-4,600'-268' OA - ? Holes	Yes	Top of frac @ 4,300'. Good volume from 4,300' to below logging T.D. (4,598'). All perfs took frac. Did not log below fractured interval.
32	11-1-67	Salt Water	Perfs	4,288'-4,596'-308' OA - 502 Holes	Yes	Top of frac @ 3,900'. Approximately half of frac from 3,900' to 4,300'. Remainder of frac from 4,370' to 4,580'.
49	9-28-67	Salt Water	Perfs	4,322'-4,588'-266' OA - 825 Holes	Yes	Top of frac @ 4,296'. Good volume from 4,296' to below logging T.D. (4,376'). Did not log below fractured interval.
76	10-23-67	Salt Water	Perfs Open Hole	4,356'-4,590'-234' OA - 336 Holes 4,616'-4,640'- 24'	Yes	Top of frac @ 4,330'. Good volume from 4,330' to 4,450'. Small volume from 4,450' to 4,480'. Good volume from 4,480' to 4,613'. All perfs took frac.
87	11-25-67	Salt Water	Perfs	4,175'-4,503'-328' OA - 372 Holes	Yes	Top of frac @ 4,150'. Good volume from 4,150' to below logging T.D. (4,470'). Did not log below fractured interval.
113	11-18-67	Salt Water	Perfs Open Hole	4,194'-4,465'-271' OA - ? Holes 4,468'-4,565'- 97'	Yes	Top of frac @ 4,220'. Good volume from 4,220' to 4,440'.
138	11-7-67	Salt Water	Perfs	4,422'-4,693'-271' OA - 370 Holes	Yes	Top of frac @ 4,410'. Small volume from 4,410' to 4,580'. Good volume from 4,580' to 4,704'. All perfs took frac.
181	11-29-67	Salt Water	Perfs	44,430'-4,640'-210' OA - 296 Holes	Yes	Top of frac @ 4,386'. Good volume from 4,386' to below logging T.D. (4,639'). All perfs took frac. Did not log below fractured interval.
188	11-30-67	Salt Water	Perfs	4,454'-4,670'-216' OA - 192 Holes	Yes	Top of frac @ 4,412'. Good volume from 4,412' to 4,520'. Little or no volume from 4,520' to 4,620'. Good volume from 4,620' to 4,680'.
192	10-23-67	Salt Water	Perfs Open Hole	*4,367'-4,590'-223' OA - 455 Holes* 4,603'-4,640'- 37'	Yes	*Top of frac @ 4,336'. All perfs took frac. Open hole took very little frac. Good volume from 4,336' to 4,400'. Good volume from 4,540' to* 4,590'. Small volume from 4,400' to 4,540' and from 4,590' to 4,640'.
200	11-23-67	Salt Water	Open Hole	4,190'-4,510'-320'	No	
203	11-27-67	Salt Water	Perfs	4,170'-4,471'-301' OA - 205 Holes	Yes	Top of frac @ 4,260'. Good volume from 4,260' to below logging T.D. (4,440'). Did not log below fractured interval.
224	9-23-67	Salt Water	Perfs	4,452'-4,600'-148' OA - 468 Holes	Yes	Top of frac @ 4,346'. Good volume from 4,346' to 4,480'. Small volume from 4,480' to 4,546'. None below 4,546'.
229	11-16-67	Salt Water	Perfs	4,438'-4,656'-218' OA - 390 Holes	Yes	Top of frac @ 4,394'. Good volume from 4,394' to 4,540'. Small volume from 4,540' to 4,608'. Good volume below logging T.D. (4,618'). Did not log below fractured interval.
278	11-16-67	Salt Water	Perfs	4,372'-4,512'-140' OA - 97 Holes	Yes	Top of frac @ 4,285'. Bottom of frac @ 4,500'. Good volume from 4,380' to 4,392'. Good volume from 4,420' to 4,454'.
30	1-7-68	Salt Water	Perfs	4,320'-4,564'-244' OA - 552 Holes	Yes	Top of frac @ 4,080'. Good volume from 4,080' to 4,320'. Small volume from 4,320' to 4,380'. Good volume from 4,380' to 4,480'. All perfs took frac. Did not log below fractured interval.
34	1-8-68	Salt Water	Perfs	4,231'-4,604'-373' OA - 451 Holes	Yes	Top of frac @ 4,190'. Good volume from 4,190' to 4,420'. Small volume from 4,420' to 4,580'. Bottom of frac @ 4,580'.
206	6-5-68	Salt Water	Perfs	4,149'-4,331'-182' OA - 71 Holes 4,344'-4,484'-140'	Yes	Top of frac @ 4,144'. Good volume from 4,144' to 4,292'. Small volume from 4,292' to below logging T.D. (4,322'). All perfs took frac.
50	12-8-69	Salt Water	Perfs	4,282'-4,596'-314' OA - 141 Holes	Yes	Top of frac @ 4,272'. Good volume from 4,272' to 4,426'. Small volume from 4,426' to below logging T.D. (4,598'). All perfs took frac.
237	1-5-69	Salt Water	Perfs	4,454'-4,662'-208' OA - 293 Holes	Yes	Top of frac @ 4,408'. Good volume from 4,408' to 4,606'. Small volume from 4,606' to 4,640'.

Average—50,000 to 100,000 bbl cumulative primary oil production.

Below average—below 50,000 bbl cumulative primary oil production.

Primary performance rating was average for wells fractured with lease oil, slightly below average for wells fractured with refined oil, and average for wells fractured with salt water. In addition, primary performance rating was slightly below average for all the wells that were fractured. Refer to Table 7 for the primary performance rating of each individual well.

Wells fractured with lease oil had an average damage ratio of 7.4, wells fractured with refined oil had an average damage ratio of 3.5, and wells fractured with salt water had an average damage ratio of 5.9. In addition, the average damage ratio for all the wells that were fractured was 5.3. Refer to Table 10 for the damage ratios of each individual well.

CONCLUSIONS

As a result of the investigation described in this paper, the following conclusions are made.

1. In the 40 fracturing treatments analyzed, oil-base fracturing fluid was superior to water-base fracturing fluid. Rated in the order of economic return, wells fractured with lease oil ranked first, wells fractured with refined oil ranked second, and wells fractured with salt water ranked third. A comparison of profit indicators (after F.I.T.) for each type of fracturing fluid is tabulated below:

	Lease Oil	Refined Oil	Salt Water
Annual Rate of Return (%)	100	100	100
Net Profit Per Dollar Invested ($/$)	2.41	2.20	0.98
Payout (Yrs)	0.24	0.48	0.56

2. Overall results of the 40 fracturing treatments were good. Profit indicators (after F. I. T.) for the entire fracturing program are listed below:

Annual Rate of Return (%)	100
Net Profit Per Dollar Invested ($/$)	1.47
Payout (Yrs)	0.47

REFERENCES

1. Petroleum Production Engineering Company: PVT Analysis Report—Shafter Lake San Andres Unit Well No. 95, (July 29, 1955).
2. Gusky, W. H. and Gulledge, M. C.: Program No. M7000—Design of Hydraulic Fracture Treatments, IBM 1130 User's Manual—Midland Division—Mobil Oil Corporation (May, 1970)
3. Smith, John E.: Design of Hydraulic Fracture Treatments, SPE Paper No. 1286—40th Annual Fall Meeting of the SPE of AIME—Denver, Colorado (Oct. 3-6, 1965).
4. Smith, John E.: Hydraulic Fracture Treatment Design:, *Twelfth Annual Southwestern Petroleum Short Course Proceedings* (April 22-23, 1965), 65.
5. Lewis, K. W. and Nathan, C. E.: Program No. M7006—Well Reconditioning Review, IBM 1130 User's Manual—Midland Division —Mobil Oil Corporation (July, 1970).
6. Smith, John E.: Well Reconditioning Review, Quarterly Well Reconditioning Reviews — Midland Division — Mobil Oil Corporation (Sept. 8, 1966), (Nov. 4, 1966), (May 8, 1967), (June 5, 1967), (March 29, 1968).
7. Arps, J. J.: Estimation of Primary Reserves, *Trans.*, AIME (1956) 207, 182.
8. Schoemaker, R. P.: Graphical Method For Solving Production Decline Problems, *World Oil* (Oct., 1967), 123.
9. Lease Income and Expense Statement Report — Midland Division — Mobil Oil Corporation (1969).
10. Smith, John E.: Prediction of the Orientation and Azimuthal Direction of Induced Fractures, *Fourteenth Annual Southwestern Petroleum Short Course Proceedings* (April 20-21, 1967), 13.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to the management of Mobil Oil Corporation for permission to publish this paper. Gratitude is also extended to the personnel of Mobil Oil Corporation for their assistance in preparing the paper.

TABLE 9
SELECTIVITY DATA

Well No.	Workover Completion Date	Frac Fluid Type	Blocking Agent Type	Blocking Agent Quantity (Lbs)	Number Blocking Agent Stages	Blocking Agent Action	Remarks
80	12-11-67	Lease Oil	Napthalene	2,500	5	Poor	Obtained only two 50 psi increases on first two stages.
179	12-5-67	Lease Oil	Napthalene	2,000	5	Fair	Obtained one 200 psi increase.
180	10-5-67	Lease Oil	Napthalene	1,250	5	Fair	Obtained three 100 psi increases.
21	4-10-68	Lease Oil	Napthalene	2,500	5	Poor	Obtained slight pressure increase.
115	4-2-68	Lease Oil	Napthalene	1,500	5	Poor	No appreciable pressure increases.
22	10-16-67	Refined Oil	Napthalene	1,250	5	Fair	Obtained 40 to 50 psi increase on each stage.
53	12-7-67	Refined Oil	Napthalene	1,500	5	Poor	No appreciable pressure increases.
85	2-27-68	Refined Oil	Napthalene	2,000	5	Poor	No appreciable pressure increases.
141	4-8-68	Refined Oil	Napthalene	1,500	5	Poor	No appreciable pressure increases.
3	6-28-69	Refined Oil	RCNBS *	2	1	Good	Screened out.
3	6-28-69	Refined Oil	RCNBS *	6	3	Good	Obtained 100 psi increase on each stage.
8	1-9-69	Refined Oil	Unibeads	600	5	Poor	Obtained one 50 psi increase.
23	10-17-69	Refined Oil	Rock Salt	400	4	Excellent	Obtained total pressure increase of 600 psi.
86	1-8-69	Refined Oil	Unibeads	1,000	5	Poor	No appreciable pressure increases.
109	1-15-69	Refined Oil	Unibeads	700	4	Excellent	Obtained 800 psi increase on fourth stage.
154	1-15-69	Refined Oil	Unibeads	700	4	Poor	No appreciable pressure increases.
205	1-15-69	Refined Oil	Unibeads	600	6	Fair	Obtained total pressure increase of 200 psi.
245	1-3-69	Refined Oil	Unibeads	1,000	5	Poor	No appreciable pressure increases.
253	2-4-69	Refined Oil	Unibeads	600	5	Poor	No appreciable pressure increases.
20	11-18-67	Salt Water	Rock Salt	2,500	5	Good	Obtained good pressure increase on each stage.
32	11-1-67	Salt Water	Rock Salt	1,500	5	Fair	Obtained 50 to 100 psi increase on each stage.
49	9-28-67	Salt Water	Napthalene	750	3	Excellent	Obtained one 600 psi and one 300 psi increase.
76	10-23-67	Salt Water	Rock Salt	2,500	5	Poor	No appreciable pressure increases.
87	11-25-67	Salt Water	Rock Salt	3,500	5	Good	Obtained pressure increase on each stage, but pressure dropped back after initial increase.
113	11-18-67	Salt Water	Rock Salt	1,000	4	Excellent	Obtained 400 to 500 psi increase on each stage.
113	11-18-67	Salt Water	Rock Salt	1,500	3	Good	Obtained good pressure increase on each stage.
138	11-7-67	Salt Water	Rock Salt	4,000	5	Excellent	Obtained 100 to 250 psi increase on each stage.
181	11-29-67	Salt Water	Rock Salt	2,500	5	Excellent	Obtained 200 to 300 psi increase on each stage.
188	11-30-67	Salt Water	Rock Salt	2,500	5	Excellent	Obtained 500 to 800 psi increase on each stage.
192	10-23-67	Salt Water	Rock Salt	1,500	5	Poor	Obtained one definite pressure increase on first stage.
200	11-23-67	Salt Water	Rock Salt	2,500	5	Good	Obtained good pressure increase on each stage.
203	11-27-67	Salt Water	Rock Salt	1,900	5	Good	Obtained 200 to 400 psi increase on each stage.
224	9-23-67	Salt Water	RCNBS *	400	400	Poor	No appreciable pressure increases.
229	11-16-67	Salt Water	Rock Salt	2,300	5	Good	Obtained 200 to 400 psi increase on each stage.
278	11-16-67	Salt Water	Rock Salt	2,400	5	Good	Obtained 200 to 400 psi increase on each stage.
30	1-7-68	Salt Water	Rock Salt	1,500	5	Good	Obtained 100 psi increase on each stage.
34	1-8-68	Salt Water	Rock Salt	3,500	5	Good	Obtained 200 to 400 psi increase on each stage.
206	6-5-68	Salt Water	Rock Salt	900	3	Poor	No appreciable pressure increases.
206	6-5-68	Salt Water	RCNBS *	60	60	Good	Obtained good pressure increase on each stage.
50	12-8-69	Salt Water	Unibeads	1,000	5	Poor	No appreciable pressure increases.
237	1-5-69	Salt Water	None	0	0	--	--

* - RCNBS - Rubber Covered Nylon Ball Sealers

TABLE 10
DAMAGE RATIO DATA

Well No.	Workover Completion Date	Frac Fluid Type	Theoretical Productivity Ratio (Dimensionless)	Actual Productivity Ratio (Dimensionless)	Damage Ratio (Dimensionless)
80	12-11-67	Lease Oil	1.9	8.4	4.4
179	12- 5-67	Lease Oil	1.9	8.1	4.3
180	10- 5-67	Lease Oil	1.9	6.3	3.3
21	4-10-68	Lease Oil	1.9	35.5	18.7
115	4- 2-68	Lease Oil	1.9	12.3	6.5
22	10-16-67	Refined Oil	1.9	23.0	12.1
53	12- 7-67	Refined Oil	1.9	6.5	3.4
85	2-27-68	Refined Oil	1.9	0.8	0.4
141	4- 8-68	Refined Oil	1.9	7.5	3.9
3	6-28-69	Refined Oil	1.9	12.0	6.3
8	1- 9-69	Refined Oil	1.9	3.7	1.9
23	10-17-69	Refined Oil	1.9	2.9	1.5
86	1- 8-69	Refined Oil	1.9	1.5	0.8
109	1-15-69	Refined Oil	1.9	6.7	3.5
154	1-15-69	Refined Oil	1.9	8.5	4.5
205	1-15-69	Refined Oil	1.9	4.1	2.2
245	1- 3-69	Refined Oil	1.9	5.3	2.8
253	1- 4-69	Refined Oil	1.9	4.0	2.1
20	11-18-67	Salt Water	1.9	33.0	17.4
32	11- 1-67	Salt Water	1.9	3.8	2.0
49	9-28-67	Salt Water	1.9	3.0	1.6
76	10-23-67	Salt Water	1.9	3.1	1.6
87	11-25-67	Salt Water	1.9	23.3	12.3
113	11-18-67	Salt Water	1.9	28.0	14.7
138	11- 7-67	Salt Water	1.9	1.9	1.0
181	11-29-67	Salt Water	1.9	15.8	8.3
188	11-30-67	Salt Water	1.9	8.6	4.5
192	10-23-67	Salt Water	1.9	1.0	0.5
200	10-23-67	Salt Water	1.9	25.0	13.2
203	11-27-67	Salt Water	1.9	4.0	2.1
224	9-23-67	Salt Water	1.9	1.4	0.7
229	11-16-67	Salt Water	1.9	26.5	13.9
278	11-16-67	Salt Water	1.9	8.3	4.4
30	1- 7-68	Salt Water	1.9	1.0	0.5
34	1- 8-68	Salt Water	1.9	7.7	4.1
206	6- 5-68	Salt Water	1.9	13.5	7.1
50	12- 8-69	Salt Water	1.9	7.8	4.1
237	1- 5-69	Salt Water	1.9	7.8	4.1