A Successful Glorieta - San Angelo Waterflood Snyder Field, Howard County, Texas

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INTRODUCTION

The Snyder Field is located in southeast Howard County, approximately 15 miles southeast of the City of Big Spring, Texas. The field was discovered in May, 1926, with the completion of the Magnolia Petroleum (Choate and Henshaw) No. 1, M. H. O'Daniel Well. The field covers 6000 productive acres and production is obtained from approximately 400 wells. The Snyder Field is south of the Iatan-East Howard Field and is separated from that field by an arbitrary dividing line utilized by the Texas Railroad Commission in distinguishing between the fields.

The portion of the Snyder Field reviewed in this paper includes the leases operated by Barranca Oil and W F Company. There are 13 leases with 65 producing wells and 30 newly-drilled water injection wells on these properties.

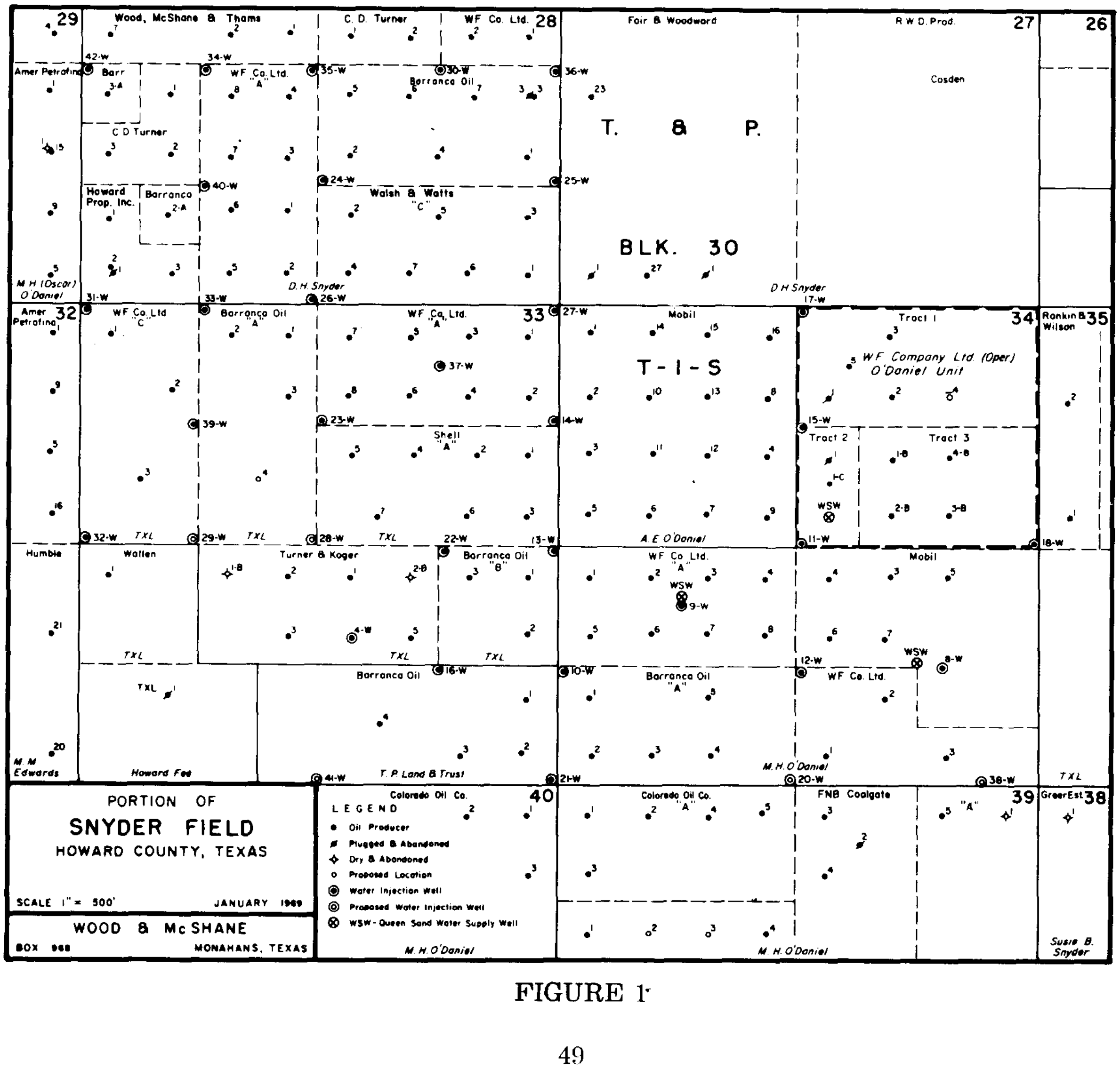

FIGURE 1

A plat of the study area is shown in Fig. 1. Barranca Oil and W F Company acquired all of these leases from other operators for the purpose of conducting waterflood operations. Wood and McShane, Consulting Petroleum Engineers, have operated the properties since the acquisitions by Barranca and W F Company.

GEOLOGY

The Snyder Field is situated geologically on the western edge of the Eastern Shelf Area of the Permian Basin. The field lies between the Howard-Glasscock Field to the south and the Iatan-East Howard Field to the north. The structure is a northeast-southwest trending, irregularly shaped anticline. It is an anticline of low relief and is joined to the Iatan-East Howard Field structure on the north by a saddle in a continuous productive belt. The producing zone is the San Angelo member of the Permian System at approximately 2600 ft.

The San Angelo member is composed of dolomite, sand, and shale. The dolomites are tan to grey, generally fine crystalline, and often anhydritic. Being interbedded with sandstone and shales, lithologic graduations such as sandy dolomites and shaley dolomites are present. The sandstones are grey, very fine grained, often shaley and/or dolomitic. Portions of the Snyder Field have several well-developed and productive sandstone zones totaling over 20 ft in thickness. The shales vary in color from light grey to black and some very carbonaceous, fossiliferous, coaly streaks are present.

Core data indicates vertical fracturing to be commonplace in the dolomites; however, the same interval is not consistently fractured and the fractures are known to grade laterally into zones of well-developed intergranular porosity. The fractures may be tight and well-cemented or open with some small amount of secondary mineralization present. Occasionally, porosity is very well-developed immediately adjacent to the fractured plane and diminishes to average porosity within an inch or less away from the fracture. When present, the saturated open fracture probably contributes materially to the primary recovery. Porosity in the dolomites is usually intergranular or intercrystalline although zones with some vugs are present. The highest per cent porosity is developed in thin streaks of sucrosic dolomite. Well-developed porous streaks with no oil saturation are common.

PRIMARY DEVELOPMENT

The majority of the wells on the leases included in this paper were drilled during the latter part of the 1930's. The development of the Snyder Field to the north and west of the study area occurred some 20 years later and production from these later wells was obtained as a result of fracture treatments.

Most of the wells in the study area were drilled with cable tools and were shot on initial completion with an average of 600 quarts. The wells were drilled on regular 10-acre locations and the older wells flowed after shot treatments. Probably the largest potential reported was one well, the W F Company, Limited, Snyder "A" No. 3, which was potentialed for 1482 BOPD. A typical old well from this period would have 7-in. casing cemented at approximately 2500 ft drilled to a total depth of 2800 ft and shot from 2650 ft to total depth with 600 quarts.

PRIMARY PRODUCTION

The first production from the study area was obtained from the W F Company, Limited, TXL "A" No. 1, which was completed in May, 1937. The remaining seven wells on this lease were drilled during 1938. The wells flowed for some time after completion and were gradually converted to pumping producers in their later life. The majority of the wells at the time waterflood plans were being made were pumped by pull-type jacks that were operated by central powers. A few of the wells had individual pumping units and in most cases the units were connected to a pull-type jack on another well so that one unit would pump two wells. Nearly all of the engines were powered by natural gas; however, electricity was available in the area.

The best lease in the field from a primary production basis is the W F Company, Limited, Snyder "A" Lease, containing 8 producing wells and 80-acres. This lease had produced 703,121 barrels of oil as of January 1, 1963. The primary recovery from this lease, therefore, was 88,000 B/W or 8800 B/Ac. The Snyder "A" Lease was also one of the older producing leases; six of the wells were drilled in 1938 and the remaining two wells were completed in 1939. An over-all average for all the leases, including 65 wells, shows a primary recovery of 40,193 B/W. If it is assumed that each well drained 10 acres, as most of the wells were drilled on 10-acre spacing, this would result in an average recovery of 4019 B/Ac. for the project area by primary producing means.

Since no gas sales were made, there is no record of gas production. No records were kept of water production, but old-timers in the area estimate water production would not exceed 10 to 15 per cent of total oil produced.

WATERFLOOD HISTORY

The early waterfloods in West Texas were confined almost entirely to fields producing from sand reservoirs. Recent years have seen a continued increase in the number of waterflood projects in operation in fields producing from carbonate reservoirs. In Railroad Commission District 7C, 8, and 8A there were 221 secondary recovery projects initiated from January 1, 1962 to January 1, 1966. More than two-thirds of these projects were programs involving carbonate reservoirs.

Waterflooding began in the Iatan-East Howard Field in September, 1954 when Sinclair Oil and Gas Company began water injection on their Dodge Estate Lease. This lease is located approximately three miles northeast of the subject area. The Sinclair project began with the conversion of nine producing wells to water injection. The conversion of the nine wells resulted in four 20-acre five-spots. The initial average injection rate was approximately 210 BPD per well at 75 psi pressure. The first response from the waterflood was observed in September, 1956, two years after the injection began. One of the major problems encountered in the Sinclair flood was the channeling or by-passing of water from the injection wells to the producing wells. A decision was reached in 1961 to drill new injection wells, rather than to convert old producing wells. The performance of the Sinclair flood since this decision has been much more favorable.

PILOT WATERFLOOD DEVELOPMENT

Waterflooding in the Snyder Field commenced in January, 1963. Prior to the actual commencing of the injection, efforts were made to form a cooperative flood, utilizing old producing wells with two offset operators. The delay experienced in negotiating this type of flood along with the success Sinclair was obtaining from newly-drilled injection wells in the Iatan-East Howard Field caused a decision to be made to drill new injection wells. In order to establish injection rates and pressures and other factors, a water injection well was drilled on the W F Company, Limited, O'Daniel "A" Lease, designated as No. 9-W. The No. 9-W injection well is located in the center of the lease, 660 ft from the lease lines and 450 ft from the four closest producing wells. The O'Daniel "A" Lease, produced 4046 barrels of oil during 1962, which is an average of 1.5 BPD per well. Well tests performed during January, 1963 indicated production to be approximately the same as the average for 1962. Water injection commenced in the 9-W Well on January 28, 1963 and response was observed only three days later on January 31, 1963, when the lease produced 80 barrels of oil in 24 hours.

This large production increase necessitated a request to the Texas Railroad Commission for a temporary allowable, pending a hearing for a waterflood type lease allowable. The hearing was held in March, 1963 and at that time it was reported that all of the production increase was observed in the No. 6 producing well, which had increased by March 14th to a production of 157 BOPD and 182 BWPD. No other well on the lease had shown any change in production, water or oil, at this time. The Commission first granted a lease-type allowable based on top well allowable for each well, but subject to the statewide proration pattern. This resulted in a lease allowable of only 113 BPD for the O'Daniel "A" Lease. Further conferences with the Commission finally resulted in the granting of a capacity waterflood allowable on a lease basis, exempt from shutdown days, on June 19, 1963.

COOPERATIVE PLANNING

The early response shown by the single injector pilot, along with the favorable allowable decision encouraged offset operators to enter into a cooperative waterflood plan. Under this plan of development it was proposed to drill and complete water injection wells on or near the corner of each lease. The drilling, completion and operating cost of the wells would be shared by each operator involved on a basis of the geometric percentage theoretically affecting his lease. An outstanding advantage of this type injection program is that each operator continues to produce his own producing wells. A disadvantage, of course, was that each injection well involved negotiations with at least one other operator before the well could be drilled. However, the problems to be settled were very minor as compared to problems that would be encountered in forming a waterflood unit.

DRILLING AND COMPLETION OF INJECTION WELLS

All of the water injection wells in the study area were drilled and completed under the supervision of this firm, operating under contract with W F Company, Limited and Barranca Oil, Limited. This involved a total of 30 cooperative water injection wells. Three wells were put on injection during 1963, nine more in 1964, seven more in 1965, ten in 1966. The final well in the study area was put on injection in 1967, making a total of 30 wells.

The drilling and completion of the first water injection well, No. 9-W was completed in January, 1963. During the drilling of the well, lost circulation was encountered while attempting to core, and for a period of time the core barrel was stuck in the hole. It was found in future development that in order to properly core the wells in such a low-pressure reservoir, it would be necessary to carry a relatively high-viscosity mud with a low weight. A study of the open-hole logs on the No. 9-W injection well, indicated that it would not be possible to select pay zone intervals from a log only and that coring would be necessary in order to select the pay zones. All the subsequent injection wells were drilled and cored, and a core gamma was run. After cementing the casing in the well, a gamma-ray/neutron log was run and this log was correlated with the core gamma and the well was perforated in the pay intervals, based on core analysis. Injection in all wells is through plastic-lined tubing and under a packer.

During the completion of each water injection well a straddle-type packer was run into the well and each perforated interval was straddled and broken with acid to make certain that all of the perforations were open and that the formation would accept fluid. There were no fracture-type treatments performed on any of the water injection wells.

WATER SUPPLY

The initial water supply was the Queen Sand reservoir at approximately 1450 ft in depth. The first water supply well was drilled on the W F Company, O'Daniel "A" Lease and completed at the same time as the water injection well. This well produced at the rate of approximately 1000 BPD, which was the required volume for one injection well. Additional water was gathered from the trucking companies hauling produced water in the area. Produced water was blended with the Queen Sand water to give additional supply. A chemical water analysis of the Queen Sand water supply is shown in Table 1.

TABLE 1

A SUCCESSFUL GLORIETA — SAN ANGELO WATERFLOOD
SNYDER FIELD, HOWARD COUNTY, TEXAS

CHEMICAL WATER ANALYSIS

	Sample No. 1	Sample No. 2
Specific Gravity at 60 degs. F	1.1672	1.000
pH When Received	6.9	6.7
Total Alkalinity as $CaCO_3$	20	
Supersaturation as $CaCO_3$	2	
Total Hardness as $CaCO_3$	23.389	1.000
Calcium as $CaCO_3$	5,089	550
Magnesium as $CaCO_3$	18,000	450
Sulfate as SO_4	3,119	172
Chloride as NaCl	229,549	990
Silica as SiO_2	2.3	
Iron as Fe	23.4	0.2
Turbidity Electric	56.1	
Color as Pt	7.5	

Sample No. 1 — Queen Sand Water Supply Well.
Sample No. 2 — Shallow Gravel Water Supply Well.

As additional injection wells were added to the waterflood program, two additional Queen Sand water supply wells were completed. These three wells, plus produced water from the area were the main source of supply during the first year of operation. It was determined by performance from these supply wells that another water source would be required because of the high cost of developing additional Queen Sand wells. During the second year of operation a shallow water gravel was located near the south portion of the Snyder Field. This shallow water gravel, at approximately 60 ft in depth is in contact with the surface water running in Beal's Creek. A chemical analysis of the water taken from the 60-ft gravel is also shown in Table 1. Production from the shallow gravel wells varies from 300 BPD to approximately 1000 BPD. To date, 75 shallow wells have been drilled and completed and only 35 wells remain active. This water source has required an extensive gathering system and transmission lines. Wooden tanks and plastic lines have been used throughout the water-gathering and transmission system.

WATER INJECTION FACILITIES

The total project includes 13 leases which require six small water injection stations to supply pressured injection water. Each station contains one or more 3-in. stroke triplex pumps, electrically operated. The produced water from all leases is piped to the most convenient water injection station for blending and re-injection. All injection surface lines are cement-lined and all down-hole injection tubing is baked-on plastic-coated. Very little chemical water treatment has been used since the coated and lined water system is expected to control the majority of corrosion problems.

PRODUCTION EQUIPMENT

Prior to waterflooding, the production equipment on the leases was capable of handling very limited volumes of fluid. Both gas and electric prime movers were in operation during primary production. More than 50 per cent of the wells were pulled by central powers. This equipment was not adequate to handle waterflood production volumes; therefore, a substantial investment in new high-volume production equipment was required during the expansion of the waterflood.

Pumping units in the secondary recovery operation ranged from 80,000 to 160,000 in.-lb

TABLE 2

A SUCCESSFUL GLORIETA — SAN ANGELO WATERFLOOD

SNYDER FIELD, HOWARD COUNTY, TEXAS

STATISTICAL DATA

Operator & Lease	No. Wells	Est. Acres	Cumulative Primary Prod. 1-1-63	Recovery As % of Cum. Primary	Total Waterflood Production
Barranca Oil, Ltd.:					
D. H. Snyder	7	80	299,822	34.1	102,118
T. P. Land	4	100	207,148	110.3	228,492
Snyder "A"	2	20	79,405	25.8	20,523
TXL "A"	3	80	161,754	20.0	32,379
TXL "B"	3	40	139,118	57.1	79,478
M. H. O'Daniel	5	80	64,940	100.0	64,933
W F Company, Ltd.:					
O'Daniel "A"	8	80	266,288	96.4	256,683
M. H. O'Daniel	3	60	28,366	93.3	26,468
O'Daniel Unit	8	160	219,386	52.1	114,236
TXL "A"	8	80	335,325	57.5	192,784
TXL "C"	3	80	34,245	63.5	21,760
Snyder "A"	8	80	703,121	40.1	281,853
D. H. Snyder	3	40	73,630		3,946
TOTALS	65		2,612,548		1,425,653*

*Recovery as per cent of Cumulative Primary and Total Waterflood Production is effective as of 1-1-69.

gear box rated units requiring electric prime movers from 15 to 40 horsepower. The majority of the electric prime movers are of a high slip type, utilizing a 15-minute programmer in place of the old 24-hour clock. The down-hole production equipment ranges up to 2-1/2 in. tubing equipped with 2-1/4 in. bore tubing pumps. Maximum production volume for any well approached 750 BFPD. The electric power for the entire project is furnished through a single primary meter and uses a company-owned primary distribution system.

The tank batteries on each lease are made up of a wooden gun barrel and several welded metal tanks, internally coated. No gas separators or heater treaters are required. Oil and water separation is accomplished through the use of chemicals in the gun barrel; corrosion protection is accomplished by application of liquid corrosion chemicals down the annulus. Where possible, the produced water is moved from the gun barrel water leg directly into the water injection storage tanks by gravity.

WATERFLOOD PERFORMANCE

The W F Company, O'Daniel "A" Lease is considered to be typical of the project area and has a primary recovery approximating the average for the project area. The 80-acre lease contains eight producing wells and produced approximately 3300 barrels per acre of primary recovery. Figure 1 shows the location of both production and injection wells. Table 2 provides statistical data on all of the leases. The O'Daniel "A" Lease as shown in Table 2 has recovered 266,288 bbl of primary oil to January 1, 1963 and has recovered 256,683 bbl of secondary oil to January 1, 1969. This is a secondary recovery over a six-year period of 96.4 per cent of primary. This 80-acre lease has two net water injectors, the

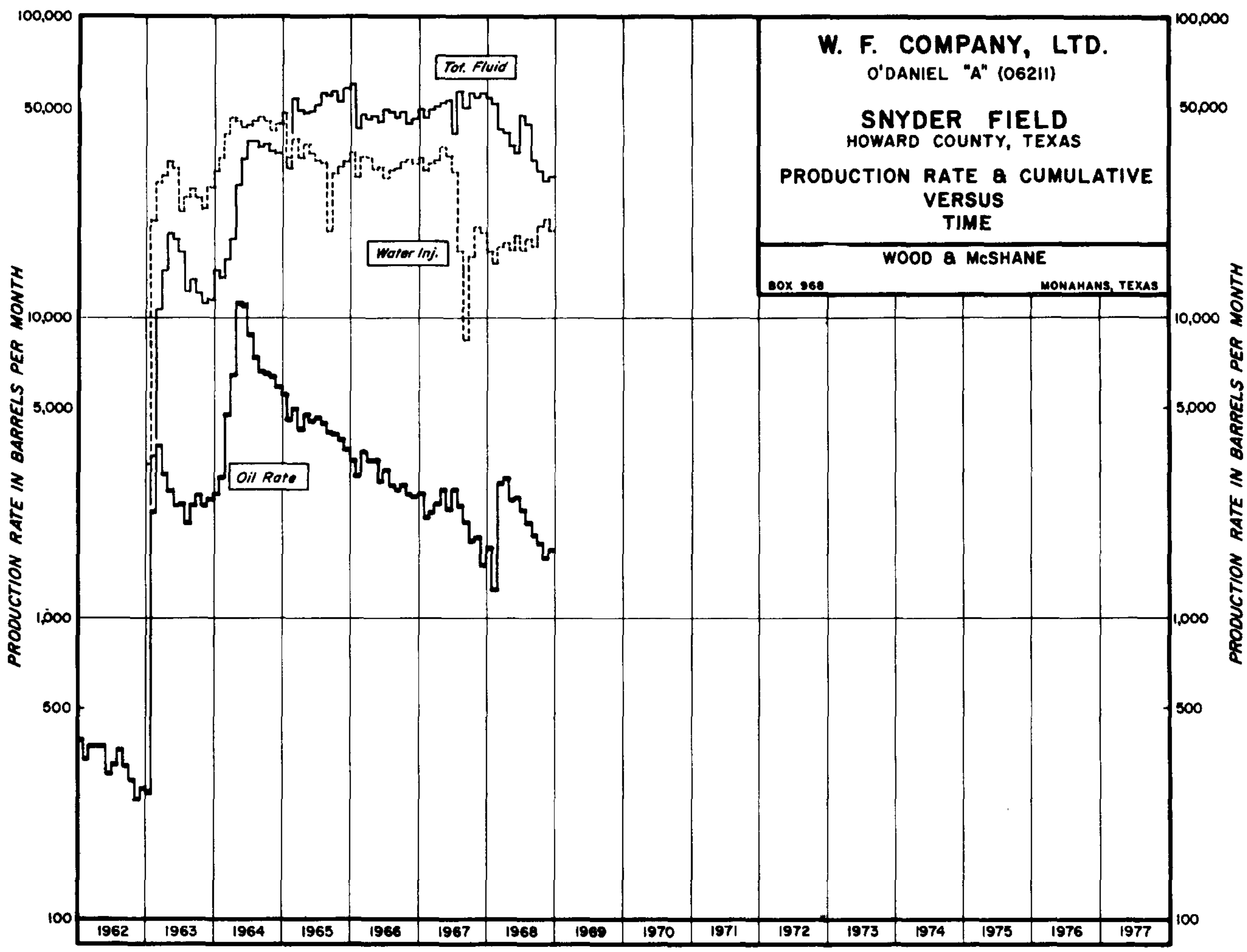

FIGURE 2

No. 9-W located in the center of the tract and one-fourth of each of the four corner wells. Total injection attributable to the lease since 1963 is 2,150,000 bbl. The largest volume of injection into a single well is 1,429,000 bbl into the No. 10-W injector. Current average injection rates are 600 BPD, and the wellhead pressure averages 450 psi. The water injected to secondary oil produced ratio is 8.3 to one. The cumulative produced water/oil ratio for the O'Daniel "A" Lease is 10.2 to one.

It is difficult at this time to forecast the ultimate recovery from this lease due to the fact that three of the eight producing wells have not yet responded to waterflood. Figure 2 is a production and injection curve, rate versus time, for this lease. The production increase in March of 1968 was achieved by closing-in one of the then active producing wells. It is assumed that increased production can be achieved through remedial work to be performed on the various injection wells involved. It is also expected that the direction of sweep now being exerted can be changed through the shutting-in or plugging of high water-cut producing wells.

The statistical data for the project as shown by leases in Table 2 includes 65 producing wells with a cumulative primary production of 2,610,000 bbl. As of January 1, 1969, the secondary recovery had been 1,426,000 bbl, which is 54.6 per cent of primary. Figure 3 is a composite production curve for the project for 1962 through 1968. The average age of the total flood project is 4.4 years through January 1, 1969. As shown in Table 2 the Barranca Oil, Limited, T P Land and Trust Lease has recovered 110 per cent of primary, which is the largest secondary to primary recovery ratio. The lowest recovery is exhibited in the Barranca, TXL "A" Lease, which has recovered 20 per cent of primary. Calcula-

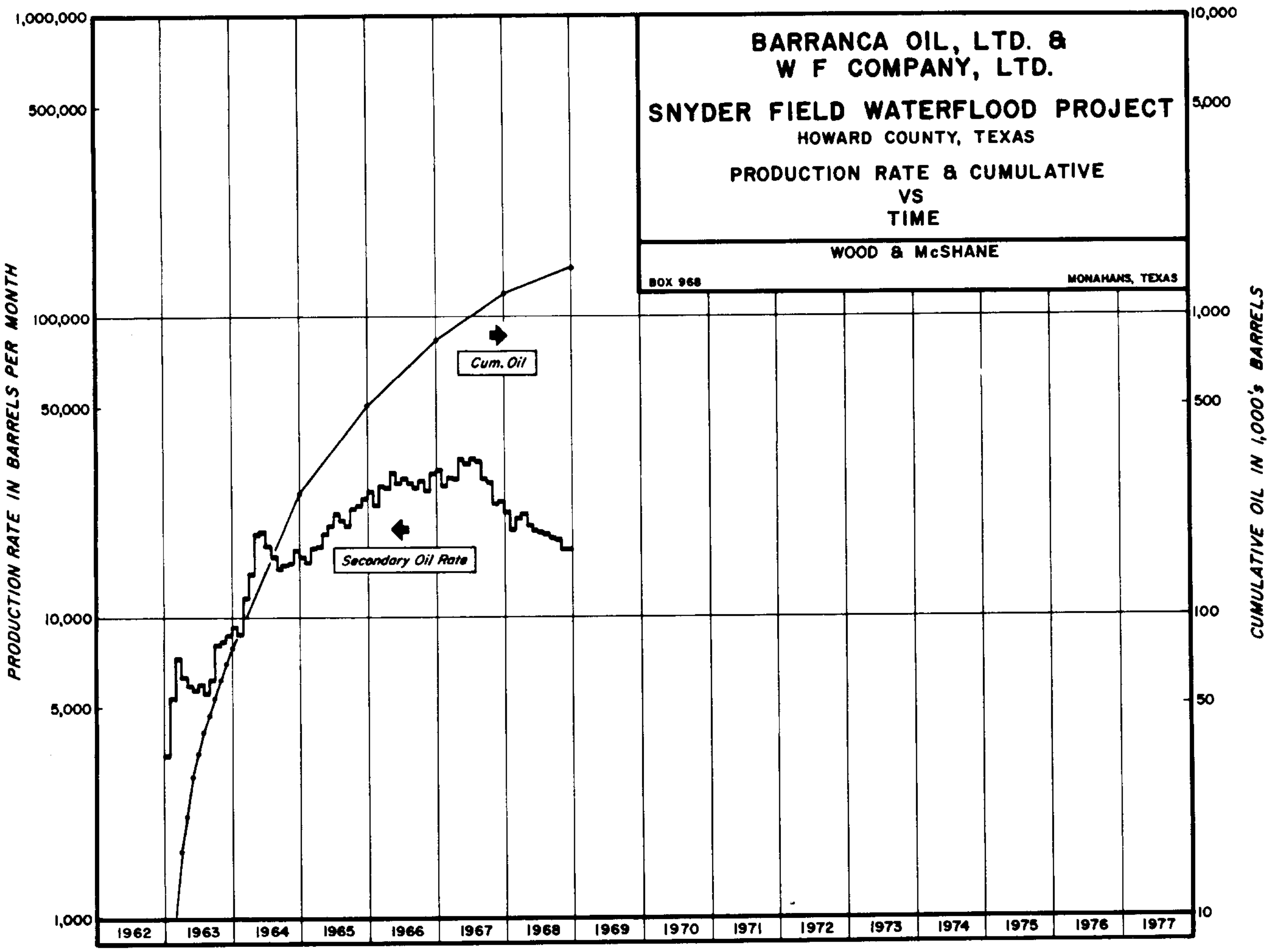

FIGURE 3

tions, including all of the projects, indicate that average secondary recovery will be 95 per cent of primary. The cumulative injection is 13,689,-000 bbl which resulted in a cumulative water-injected to oil-production ratio of 9.6 to one. The cumulative produced water/oil ratio is 4.4 to one through January 1, 1969.

A study based on decline curve analysis for the project area indicates the average flood life will be 10.5 years for each lease. It is also noted the average injection well density is one net injector per 54 productive flood acres.

PROBLEMS AND SOLUTIONS

In 1962 the problems with regard to waterflooding in the Snyder Field were very few. In fact there seemed to be only two problems at that time, floodability of the reservoir and the availability of an adequate water supply. There was no shallow water reservoir in the area of the Snyder Field that had the adequate production capacity to properly supply a waterflood project. Therefore, the first water supply used was the Queen Sand reservoir at 1450 ft. After completing three Queen Sand supply wells and producing them for several months it was determined that additional sources would be necessary. The shallow water gravel located along Beal's Creek at the south end of the Snyder Field was then developed. This shallow gravel was limited in its production capacity and many small wells were needed to produce a sustained large volume of injection water. The shallow gravel water was non-potable and was far superior for injection purposes to the Queen Sand water. In order to obtain an adequate supply it was necessary to acquire water rights under eight sections of land in addition to permission from the State of Texas to withdraw water from the creek itself. This water system has supplied all of the make-up injection water for the entire Snyder Field up to the present time. This volume averages 15,000 BPD.

Water compatibility problems have been expected, but to date have not developed to any serious degree. The fact that Queen Sand water, produced water, and shallow gravel make-up water have all been blended into the system in varying percentages has made chemical treatment for corrosion and/or scale impractical.

One outstanding discovery that has come out of this rather complex water supply is the fact that in this type of carbonate reservoir the water quality required is very low. Well-bore damage due to plugging has not been apparent even after more than 1,000,000 barrels injection in a given well. Injection well pressures remain at a low 500 psi and in most cases injection wells are throttled at the surface in order to control injection rates. It is our opinion that the quality of injection water into a reservoir of this type is of secondary importance.

The floodability of the reservoir was a definite question since the majority of the wells in the project area had been drilled by cable tools and there was very little core data available. Drillers' logs, sample logs, and original completion data along with primary oil production histories represented the majority of the information available for the beginning of the waterflood operation.

Because of the limited reservoir data available it was deemed advisable to core the first few injection wells so that reservoir conditions could be better determined. The W F Company, O'Daniel "A" No. 9-W Well, which was the first injector, was cored from the top of the San Angelo reservoir down into the top of the Clearfork reservoir. This core proved to be very interesting in that it indicated three conditions that would directly affect the floodability of the reservoir. These conditions were porosity development without saturation, or dry porosity, fractures in the pay zones, and proof of the variation in permeabilities in the pay section.

The dry porosity was found to exist in the core analysis and it was indicated as porosity in open-hole logs. It was felt that it would be desirable to eliminate all dry porosity in the completion of all injection wells.

Some fractures in the main pay sections were shown to have been open in the reservoir, because of secondary solution porosity adjoining the fracture itself. Other fractures were determined to be near the zones of weakness that would break during the coring operation. Since the fractures did not exist in all of the pay, an effort was made to complete the 9-W Injector in such a way as to exclude the fractured zone.

The permeability and porosity found in the 9-W core indicated a relatively high average porosity in the pay section of approximately 15 per cent with a permeability variation from 1 millidarcy to 200 millidarcies. Average conditions across the project as a whole were found to be 15 to 17 per cent porosity with permeabilities averaging from 10 to 30 millidarcies. These millidarcy figures do not include any fractured permeability. After drilling and coring the first injection well, an open-hole log series was run as well as a cased-hole gamma ray neutron. A correlation from core gamma to gamma ray neutron was utilized in perforating the zones selected for injection. The well was cemented with various mixes of cement, but primarily opposite the pay zone, a latex-cement slurry was used in conjunction with centralizers and scratchers. Zones selected for injection were perforated one hole at a time and then each zone of injection was selectively acid-washed between packers. The selective acidizing not only assured each zone being open but also gave information regarding zones of communication. In the initial well, injection was commenced at the rate of 12 to 1400 BWPD at a zero wellhead pressure. Three days later a first response occurred in the O'Daniel "A" No. 6 producer, which was located approximately 450 ft from the injection well. A tracer survey run on the 9-W injector indicated that the zones selected for injection were taking water and that the fractured zone was not in communication at the well-bore. Therefore, it was determined to increase the production capacity in the producing well and continue injection and production. Within 60 days the No. 6 O'Daniel Well had increased to approximately 350 barrels of total fluid, 150 barrels of oil and 200 barrels of water.

Since the initial injection well core analysis did indicate varying problems existed, it was determined to continue coring all injection wells. This practice has been continued throughout the life of the project. Another interesting factor which is involved in the make-up of the reservoir is the direction of fluid movement.

It became apparent as development continued that a fairly well-defined direction of fluid movement could be expected, and this direction tended to be east-west with more movement west than east. This line of movement has been directly observed from the No. 12-W injector in the south-east corner of the O'Daniel "A" Lease to the O'Daniel "A" No. 5 producer, approximately four locations or one-half mile west. A similar situation occurred in the W F Company, TXL "A" No. 37-W, which communicated directly to the W F Company, TXL "C" No. 2 producer, approximately one-half mile west. Other occurrences of water breakthrough have been observed and are expected to continue to occur as the flood area in the Snyder Field expands.

In our opinion it is doubtful that the problems of directional water breakthrough can be corrected using present-day technology. Therefore, we have attempted to use this condition to the flood advantage, through shut-in producers acting as pressure back-up wells. Changes in the sweep pattern have been shown by increased oil production obtained through this technique. At a later time in the life of the flood, it may be desirable to convert producing wells with the water breakthrough condition to water injection.

CONCLUSIONS

After six years of waterflood performance in the Snyder Field, the following conclusions can be made:

1. The San -Angelo-Glorieta reservoir, as described herein, can be successfully waterflooded utilizing newly drilled and completed water injection wells.
2. An average condition under waterflood operations would include high water/oil ratios, and a secondary recovery equal to ultimate primary recovery.
3. High water-injection rates can be used and injection water quality does not seem to affect injection rates and pressures.
4. Visual inspection of cores and careful study of core analysis data have been of vital importance in selecting the desirable pay zones for injection.
5. Analyses of active waterfloods in the Iatan-East Howard and Snyder Fields indicate the optimum injection well density is one new injector per 80 acres.