SOCIETY OF PETROLEUM ENGINEERS OF AIME
6300 North Central Expressway
Dallas, Texas 75206

PAPER NUMBER SPE 1157

CYCLIC STEAM INJECTION IN THE QUIRIQUIRE FIELD OF VENEZUELA

By

R. W. Payne, Member AIME, and Gabaniel Zambrano,
Creole Petroleum Corp., Quiriquire, Venezuela

This paper has been previously presented at the Simposio de Recuperación de Petróleo por Métodos Térmicos, sponsored by the Sociedad Venezolana de Ingenieros de Petróleo, March 4-6, 1965, at the Colegio de Ingenieros de Venezuela.

ABSTRACT

For the past four years the Creole Petroleum Corporation has been actively testing the use of steam as a production stimulant in the Quiriquire Field of Eastern Venezuela. The method being tested is the so-called "huff-and-puff" method where steam is injected into the formation and the well later returned to production. This method of stimulation has been used for eight wells in the Quiriquire field. In the most successful case a well produced 60 percent more oil over a 490-day period following start of steam injection than would have been obtained had the well been produced in its normal fashion. Steam was injected for 44 days to achieve this increase in production rate. A second cycle of stimulated production was not as favorable as the first for this well.

The quantity of heat injected and the initial selection of wells for steam injection is important. In one case, a well did not produce as much oil following steaming as expected under cold conditions. Creole is planning a more extensive program of well stimulation in the Quiriquire field for application of this process.

INTRODUCTION

For the past four years, the Creole Petroleum Corporation has been actively testing the use of steam as a production stimulant in the Quiriquire Field.

The production decline has caused an aggressive program of well stimulation to be initiated. The production has declined from a maximum of 80,000 BOPD in 1951 to a minimum of 33,000 BOPD. All conventional methods of individual well stimulation have been used as well as some methods that have been developed locally. In addition to these methods, it was decided in 1959 to try heat.

The Creole Petroleum Corporation initiated the injection of steam in the Quiriquire field to observe the effect on individual well production rates.

The Quiriquire reservoir does not possess all the optimum qualities for any method of thermal stimulation. The formation is heterogeneous, the oil originally in place was considerably below 1000 barrels per acre-ft., the sands are lenticular and the producing section contains a high percentage of interlaminated shales. The one factor in favor of thermal methods is the relatively high viscosity of the oil.

It was realized at the outset of the steam injection program in Quiriquire, that the field does not possess as advantageous properties for thermal stimulation as some fields in other part of the country.

However, the fact that the field is the largest in the State of Monagas and Creole's largest in Eastern Venezuela, was sufficient incentive for testing steam as a method of halting the rapidly declining production.

The properties of saturated steam suggested that it was an appropriate agent for the transfer of heat to formation fluids. Furthermore, in Quiriquire there was abundant well water at shallow depths which was of adequate quality for boiler feed, and there was sufficient gas available for use as fuel.

This presentation will cover the results of those tests which have been carried out to date as well as our plans for future work.

LOCATION AND GEOLOGY

The Quiriquire Field is located in the eastern part of the State of Monagas about 35 kms. north of Maturin the State capital, Figure 1.

Structurally the Quiriquire reservoir is a gently dipping unfaulted monocline. The sediments of the producing formation range consist of interlaminated sands and shales. The high percentage of shales reduce the producing interval to 20 to 50% sand. It is very common to find sections where the shale-sand ratio is 5 to 1. The sands vary in size from boulders to silts, with conglomerate and gravel beds predominating. The sands are lenticular, discontinuous and unconsolidated.

GENERAL

The Quiriquire Field has about 450 active wells, Figure 2; the producing depth varies from 1300 ft. updip to 4700 ft. downdip. Gross intervals in excess of 1000 ft. are not uncommon, but shales usually reduce the net sand from 20 to 50 percent of the interval. The oil originally in place was considerably less than 1000 bbls/acre-ft.

Oil gravity ranges from 11 to 29° API and is generally quite viscous. The principal drive mechanism is solution gas drive.

STEAM - EFFECT ON VISCOSITY

The effects of temperature on the properties of steam can be represented graphically. Figure 3, taken from standard steam tables, summarizes the temperature, pressure and enthalpy data on saturated steam. The upper curve shows the temperature of wet steam as a function of pressure. Every point on the curve represents a state in which water and its vapor can exist in equilibrium. The indicated temperature is independent of the quality of the steam and is valid over the whole range from saturated water to saturated steam. The lower curve shows the heat content of both saturated steam and water at various pressures.

The following example illustrates the application of the curves: a boiler produces wet steam at 1000 psia. The temperature of this steam, as read from the pressure - temperature curve, will be 545° F. If it is known that the steam is saturated, then the total heat content is 1192 BTU per pound, as read from the lower curve.

When heat generated at the surface is transferred to a reservoir the following will occur. Not all of the heat is effectively utilized in the reservoir, since part of it will be lost by radiation from the injection lines and part will be lost from the well bore to non-productive formations. Finally the steam will condense. If the reservoir pressure is known, the heat content and temperature of the steam can be determined at this point from the curves. From an analysis similar to this it is possible to predict the maximum temperature obtainable, knowing only the reservoir pressure. (This assumes that nothing occurs that will cause significant changes in the pressure).

Thus, with a knowledge of both the reservoir parameters and the equipment being used, one can make a reasonable prediction of the quantity of heat that will enter the reservoir and the maximum temperature that can be obtained.

The effect of temperature variation on the viscosity of Quiriquire crude has been studied previously. The curve in Figure 4 was constructed using empirical equations based on 15 Quiriquire fluid analyses. It is apparent from the curve that 5 to 10 fold reductions in oil viscosity should be obtainable by reasonable increases in temperature.

The effect on production of a decrease in oil viscosity can be estimated using D'Arcy's law which indicates that the productivity of a given well is inversely proportional to the viscosity of the produced fluids.

EARLY TESTS

To test whether or not proportional oil

rate increase could be obtained, a field test was run on Q-562 in the extreme western end of the field (Figure 2) between November 1960 and July 1961.

Three methods of transferring heat to the produced fluids were tried:

1. Simultaneously injecting steam down the casing and producing the well.

2. Circulating steam in the well until a maximum bottom-hole temperature was obtained, then shutting down injection and returning the well to production.

3. The so-called "huff and puff" method where steam is injected into the formation and the well later returned to production.

There is very little which can be said about the results of the first and second methods beyond stating that they were abandoned as failures. The huff and puff test on this well can be called a qualified success.

The decline curve for well Q-562 is shown in Figure 5. This curve shows the manner in which the well was declining prior to the start of injection. After the well was prepared for the program, several production tests were made to establish its cold rate for comparison with rates after injection. This starting point was 72 BOPD. After injection the well was placed on test, and, as shown by the figure, the rate was back down to 72 BOPD within a short time. However, if the cold rate is extrapolated according to the historic decline, it is easy to see that there was an increase that must be attributable to the steam injected into the formation. The actual production from the start of the test to the present has been 140% of the projected cold rate production.

PILOT PROJECT

a) Preparations

The results obtained from the tests in well Q-562 were not good enough to justify a full scale steam stimulation program. However, they were sufficiently encouraging to warrant further investigation using better wells and more modern equipment.

To obtain a more reliable evaluation of intermittent steam injection, two boilers were acquired which would produce five times as much heat as the Lucey boiler used at Q-562 and could operate at approximately 3 times the pressure. Two 380 horsepower "Texsteam" boilers were installed, each capable of generating 10,000 lbs/hr. at a pressure of 1000 psi.

Four wells located in the heavy-oil, southeast part of the field where the average produced oil gravity is about 14.0° API were chosen for the intermittent tests.

Figure 6 shows the general layout of the wells, terrain, roads, stationary boilers and steam lines.

b) Injection Wells

Other than being better than average producers for Quiriquire, these four wells have little in common. Before steam injection, the producing rates ranged between 113 and 309 BOPD, with a historic decline between 0.3 and 1.2% per month. The gross interval (from top perforation to bottom perforation) varied from 470' to almost 1200', while the net sand open ranged from a low of 216 to a high of 422'. The producitivity indices fell between 0.2 and 1.1 B/D per psi.

c) Cycles

1st) From the results of the Q-562 tests, it was concluded that increased production rates could be achieved by this method. This four well program had as its objectives to find out how long increased rates could be sustained and how best to obtain these increases.

Each well in the program started out by receiving approximately the same quantity of steam. The response in the producing rate of each well after steaming is shown in Figure 7. Each point is a different well. The abscissa corresponds to the net sand open and the ordinate is the production rate increase expressed as a multiple of the cold test rate. Thus, the best test after steaming varied from 1.0 to 2.9 times the best test before steaming. From this figure it is seen that the increase in rate appears to vary linearly with the sand open.

Testing continued on all these wells for approximately one year. The cumulative oil recovered was compared with the recovery projected from the unstimulated declines for each well. This was done individually in order to evaluate more specifically the action of steam in obtaining increased producing rates. Figure 8 shows graphically the results of this comparison. Again, the abscissa shows net sand open, but in this case the ordinate shows the total recovery as a fraction of the projected, unstimulated recovery.

The oil recovered varied from about 60% to 160% of the projected cold rate cumulative recoveries. The 60% corresponded to a well which did not even recover the volume of oil lost while the well was taking steam.

The actual history at our best well, Q-594, is shown in Figure 9. After steaming the well was returned to production and produced for 443 days. Cold tests, immediately prior to steam injection averaged 143 BOPD. The rate after injection reached a high of 380 BOPD and ultimately fell off to cold rate, but averaged 213 BOPD during the 443 day period. This was in spite of higher back pressure being imposed on the well during this period. During the production cycle it is to be noted that a slight increase in water production from 10% to 20% occurred as a result of the steam condensate. It is interesting to note that at the very end there was still a significantly higher produced fluids temperature than normal. This is the well which recovered 160% of the projected cold rate production.

From the information obtained during this first cycle, it was concluded that:

1. Three-fold rate increases could be obtained by this method in Quiriquire.

2. Under favorable conditions, sustained increases for a year or more are possible.

3. The initial selection of which wells should receive steam is very important since wells respond to steam very differently.

2nd) About a year ago, a second round of steam injection was started in these same wells.

For the second cycle it was decided to inject a larger quantity of steam into those wells which did not respond satisfactorily on the first cycle. Of course, the effects of second round steaming on the wells which had responded satisfactorily would also be observed.

As might be expected the only really significant difference between the first and second cycles came from the well which failed to respond to first-round steaming. It is encouraging that the rest of the wells showed an immediate increase in rate very comparable to the first-round pick-up. The cumulative production data for the second cycle are not yet complete, since three of the four wells are still producing in this phase. In general, it appears that the worst we will do on any well during this cycle is break even. On three of the wells we should get some incremental oil.

A significant point is that these wells will apparently end up in the same relative position as before. That is, the best well on the first cycle will still be the best on the second, the worst will still be worst and so on. Figures 7 and 8 also give an idea of the preliminary results for the second cycle.

From this, it has been concluded that, even though the careful selection of steam candidate wells is critically important, the effect of the steam input level can not be ignored.

Figure 10 shows the performance during the second cycle of the best well, Q-594. This well declined to the cold rate in about 9 months compared to 14 months on the first cycle.

To put this in perspective with time, Figures 11 and 12 show the long term performance of our best well and worst well. Well Q-529 had a production rate of 300 BOPD before steaming. This is the well which had a final stimulation ratio of 0.60 for the first cycle and showed the poorest performance. During the second cycle it received twice as much steam, and it now appears as though it will have at least a 1.0 stimulation ratio.

Q-594 which was a 140 BOPD producer, gave incremental oil on both cycles. We believe that this well proves that increased production can be obtained by this method in Quiriquire.

From these additional data, the conclusions from the first cycle have been modified:

1. A well which responds satisfactorily to a first cycle of injection should be considered as a candidate for at least one more cycle.

2. The quantity of steam injected is significant.

3. The initial selection of which wells should receive steam is the most important part of the process. Generally, it appears that poorer wells can be helped proportionately more than better wells. There must be some limits both ways, but right now we are interested in the possible response of the poor wells.

PLANS

a) Present

These conclusions are now being put to a more rigorous test.

The original steam injection project has been expanded to include three more wells, (Figures 2 and 6). These wells with a rate between 50 and 100 BOPD should provide the necessary information for future operations. They have been selected so that the production from the best well of this new group is less than the rate from the poorest well in the initial group. These wells should show whether or not we are correct in hoping for improvement in the poorer wells. Also we hope to solve the problem of the minimum amount of heat injection which will be efficient; the program now being undertaken will have two injection phases.

Each of the three wells has received injection for a period of two weeks. The increases obtained have been relatively modest. A well which produced 77 BOPD is now making 130 BOPD two months after the end of injection. A 55 BOPD well is producing 50 BOPD a month and a half after injection, and the third well, which made 90 BOPD cold, is producing 83 BOPD a month after.

It is planned to continue producing these wells until practically all of this heat has been dissipated, after which larger quantities of steam will be injected and the wells again returned to production. A comparison of the results from these two procedures will establish some limits that will be very meaningful for Quiriquire.

A comparison of the long term response between these wells and the original four should help to define the sort of well from which best results can be obtained.

It is also planned to continue intermittent injection. It is desired to try short term injection on a stimulated well that has not declined all the way to the cold rate. We want to establish how many times this process can be repeated. In short, this steam installation will continue in operation as long as it is useful in providing additional information.

b) Future

A portable unit (Figure 13) will be more economic and much more efficient than the permanent type of installation currently in use in the Station 23 area. A skid-mounted, semi-portable water softening plant will be set at a flow station. Treated water will go from a storage tank to the steam generators through an aluminum line. Fuel gas will be transported by the individual well flowlines. Steam will be generated on location by trailer-mounted boilers.

This equipment is on order and will be placed in operation in the near future.

In addition to having a lower initial cost than a stationary steam plant, this will also have the advantage of flexibility. Wells at the edge of the field can be stimulated with this mobile plant. Some of our better prospects are in these areas, where the pressure and viscosity are comparatively high.

The economic aspects (not to mention the engineering) of transporting high pressure steam over long distances make it unlikely that these wells would ever be stimulated from a stationary plant.

SUMMARY

It should be emphasized that a conservative approach is recommended in extrapolating the results in Quiriquire to other fields of different physical properties. As was stated at the beginning, it was realized that the Quiriquire Field did not possess all the optimum qualities for steam stimulation, and the success to be encountered in the more massive and shallower reservoirs probably could not be expected here.

However, it does appear that, in spite of the somewhat difficult conditions, steam stimulation has an application in the Quiriquire Field. Up to the present time Creole has been engaged in intensive tests on a limited number of wells with the purpose of obtaining information. Creole will continue to seek information, but we believe we are ready to embark on a more extensive program with a larger number of wells.

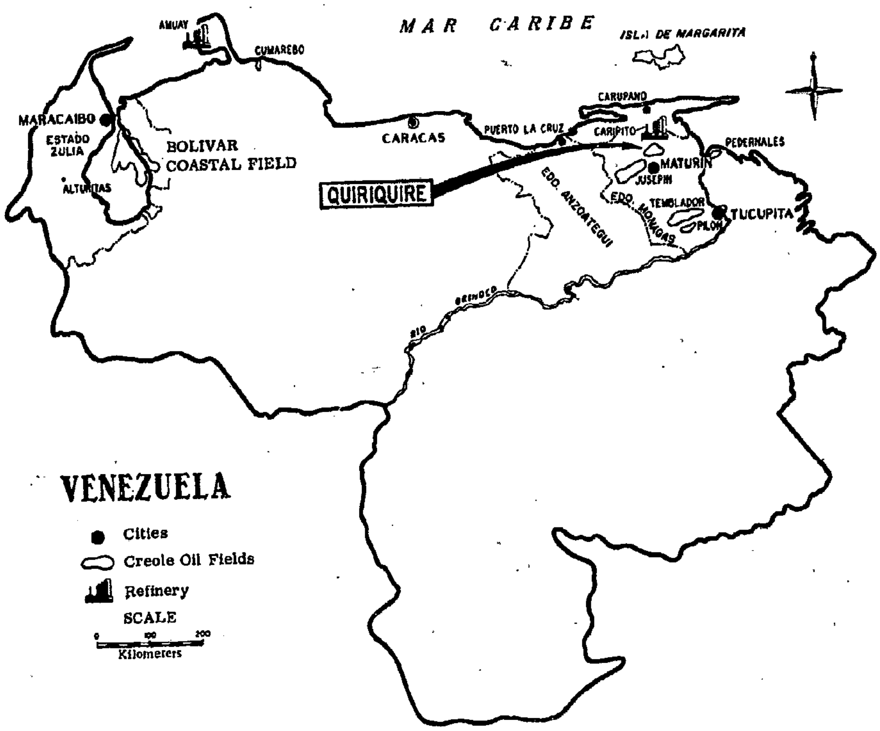


FIGURE 1

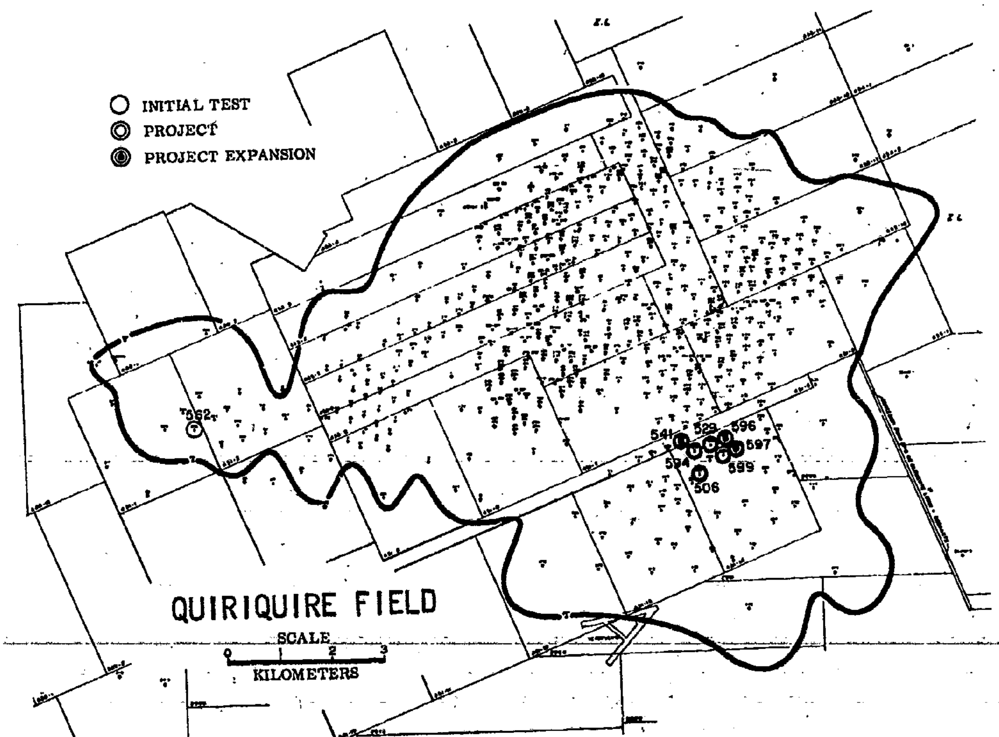


FIGURE 2

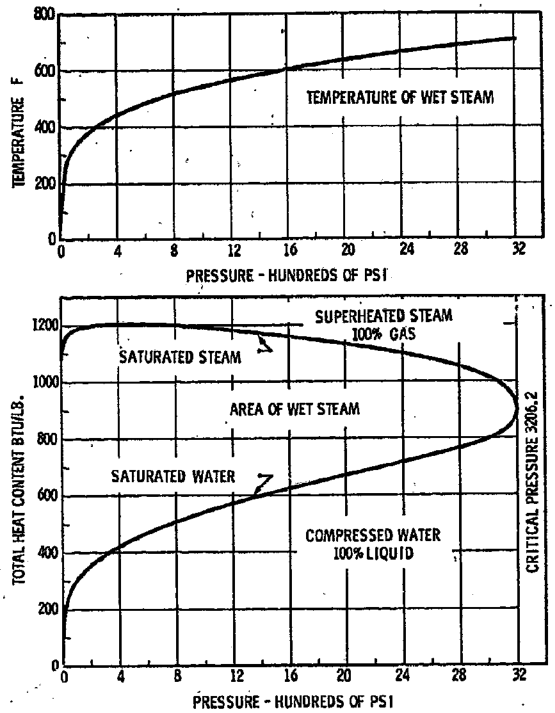


FIGURE 3

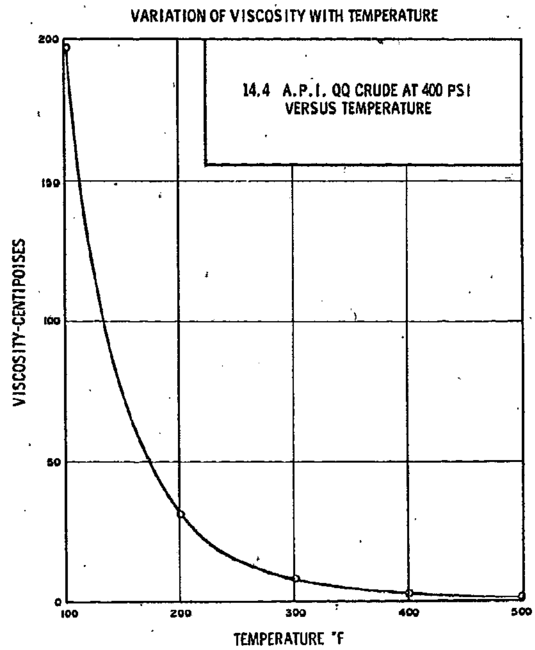


FIGURE 4

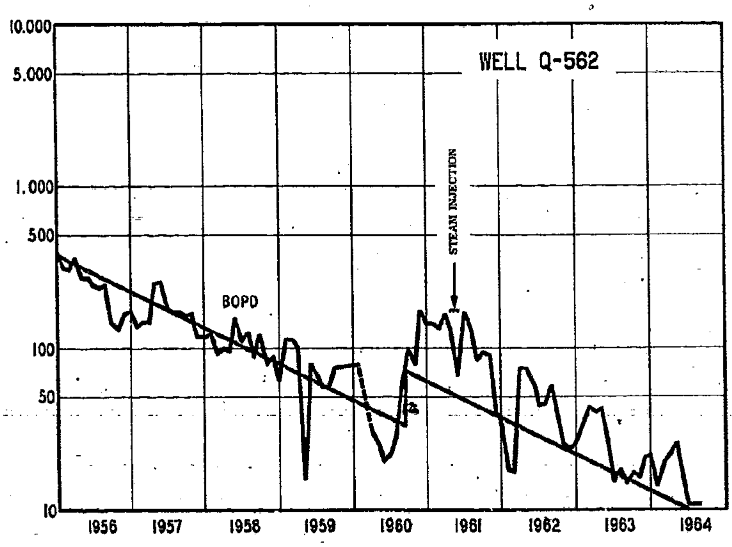


FIGURE 5

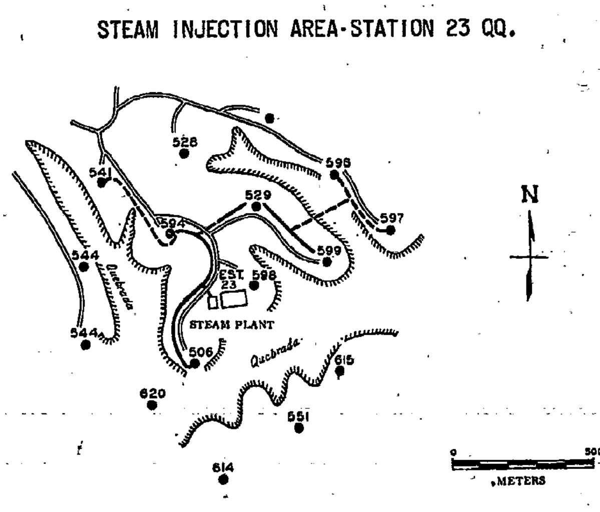


FIGURE 6

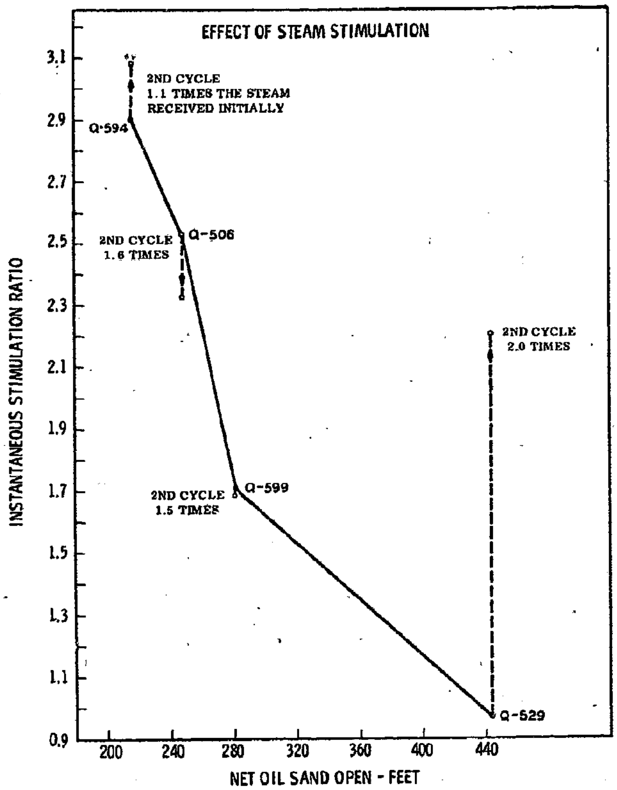


FIGURE 7

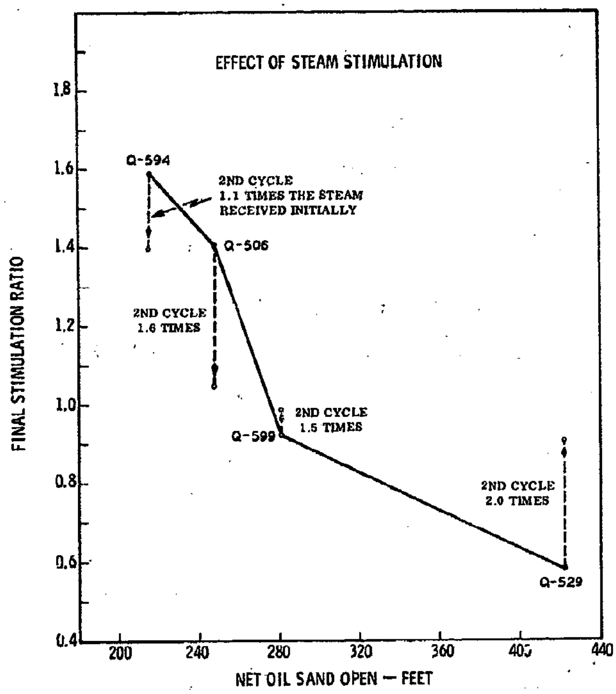
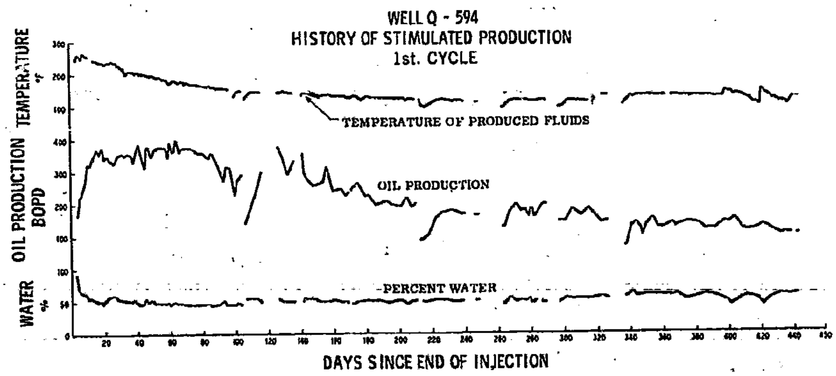


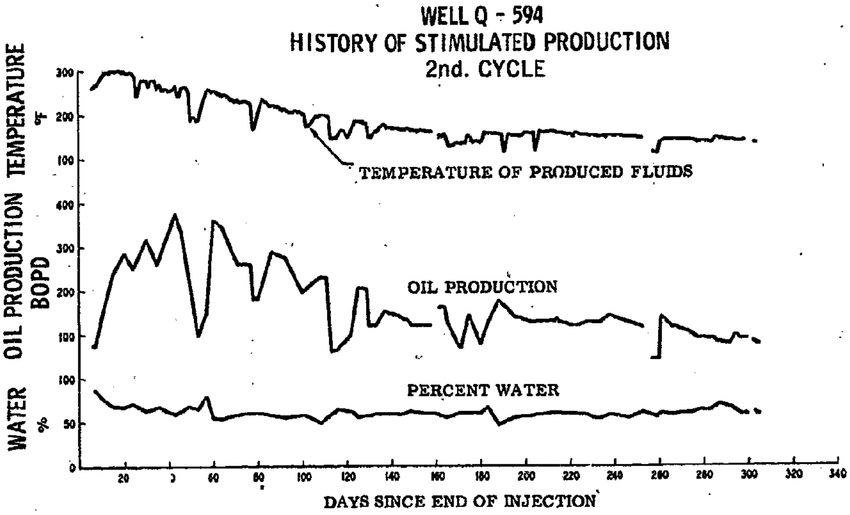
FIGURE 8



Q-594 PRODUCTION INFORMATION
FIRST CYCLE

	ORIG.	STIM.
CASING PRESS.	75	119
TEMP. OF FLUIDS	95	151
BOPD	143	213
PERCENT WATER	40	51
CUM. STIMULATION RATIO	-	1.589
DAYS ON PRODUCTION	-	443
INJECTION TIME	-	44 days

FIGURE 9



Q-594 PRODUCTION INFORMATION
SECOND CYCLE

	ORIG.	STIM.
CASING PRESS	75	145
TEMP. OF FLUIDS	95	189
BOPD	143	174
PERCENT WATER	40	62
STIMULATION RATIO	-	1.359
DAYS IN PROD.	-	305
INJECTION TIME	-	49 days

FIGURE 10

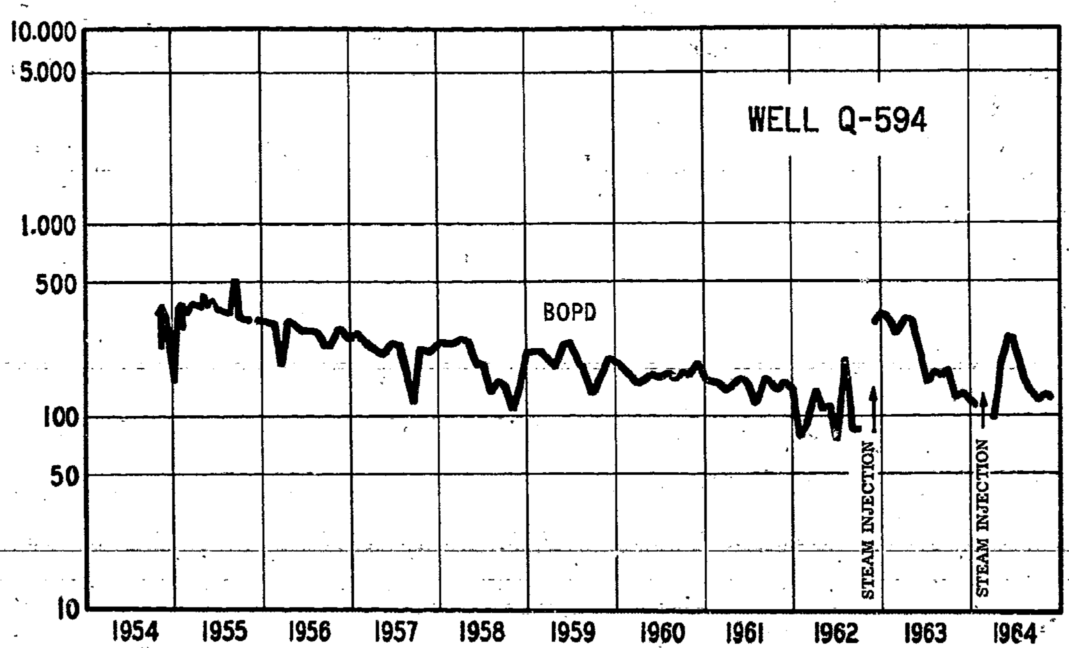


FIGURE 11

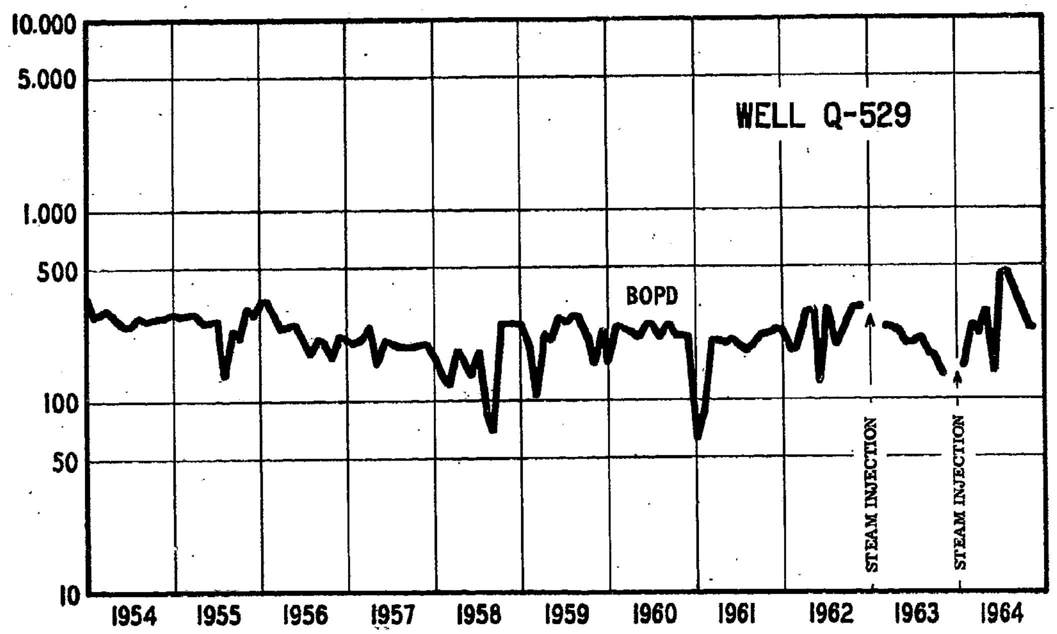
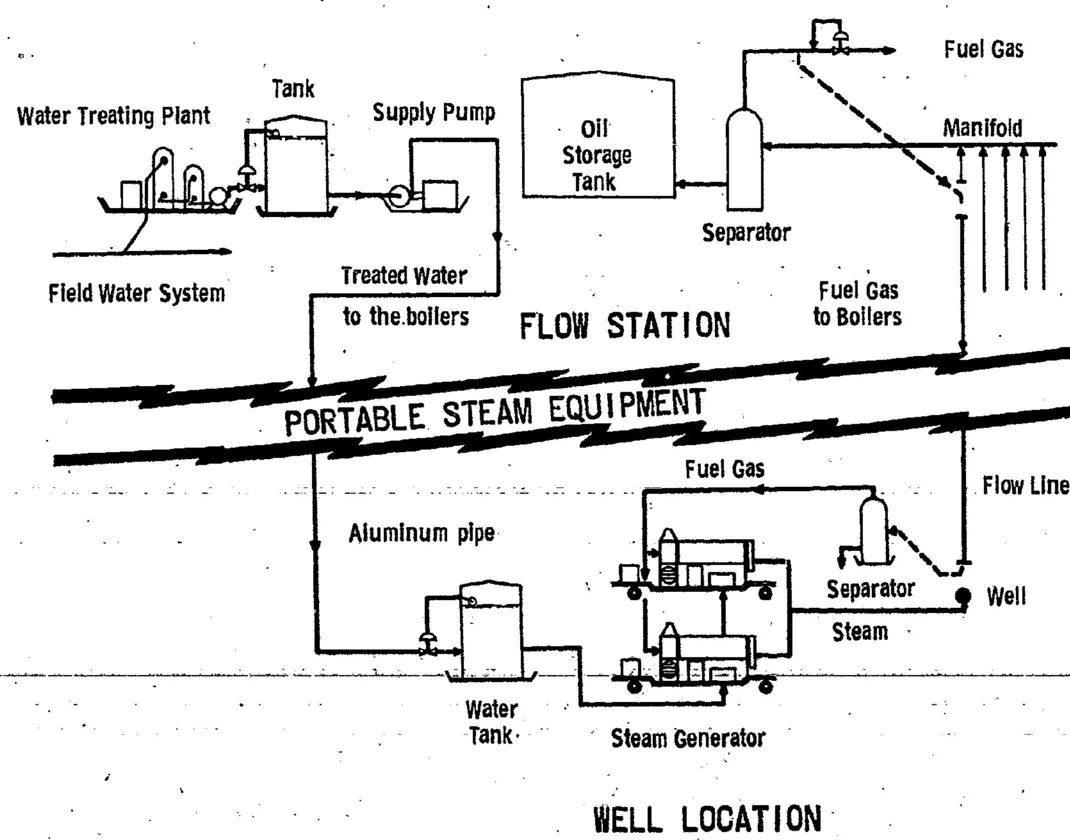

10.000
5.000
1.000
500
100
50
10
WELL Q-529
BOPD
STEAM INJECTION
STEAM INJECTION
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964

FIGURE 12


Fuel Gas
Tank
Water Treating Plant
Supply Pump
Oil Storage Tank
Manifold
Separator
Field Water System
Treated Water to the boilers
Fuel Gas to Boilers
FLOW STATION
PORTABLE STEAM EQUIPMENT
Fuel Gas
Flow Line
Aluminum pipe
Separator
Well
Steam
Water Tank
Steam Generator
WELL LOCATION