April 2, 1968 A. SATTER ET AL 3,375,870

RECOVERY OF PETROLEUM BY THERMAL METHODS

Filed Nov. 19, 1965 2 Sheets-Sheet 1

CALCULATED TEMPERATUE DISTRIBUTION, CONDUCTION HEATING FROM A FRACTURE

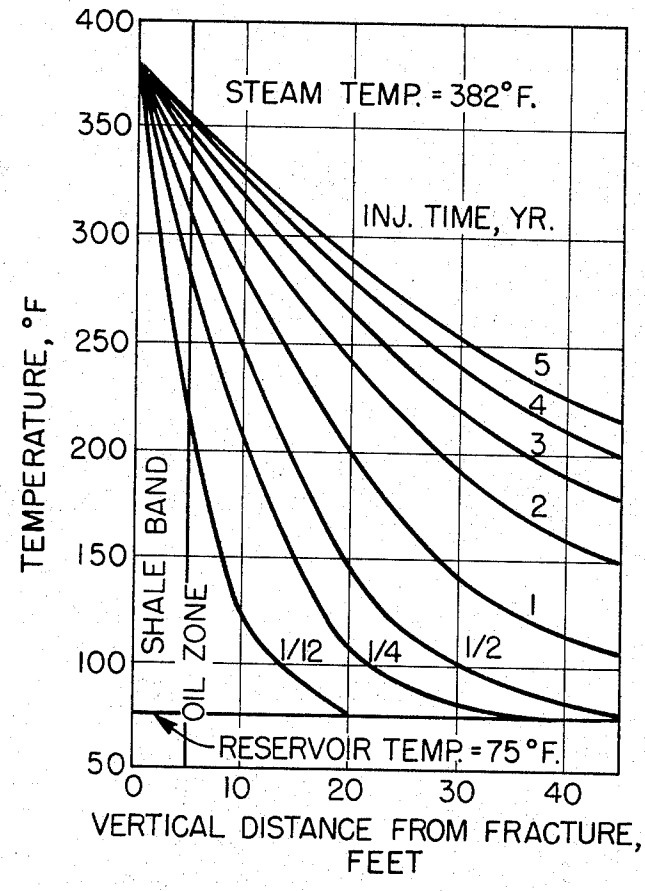


Fig. 1

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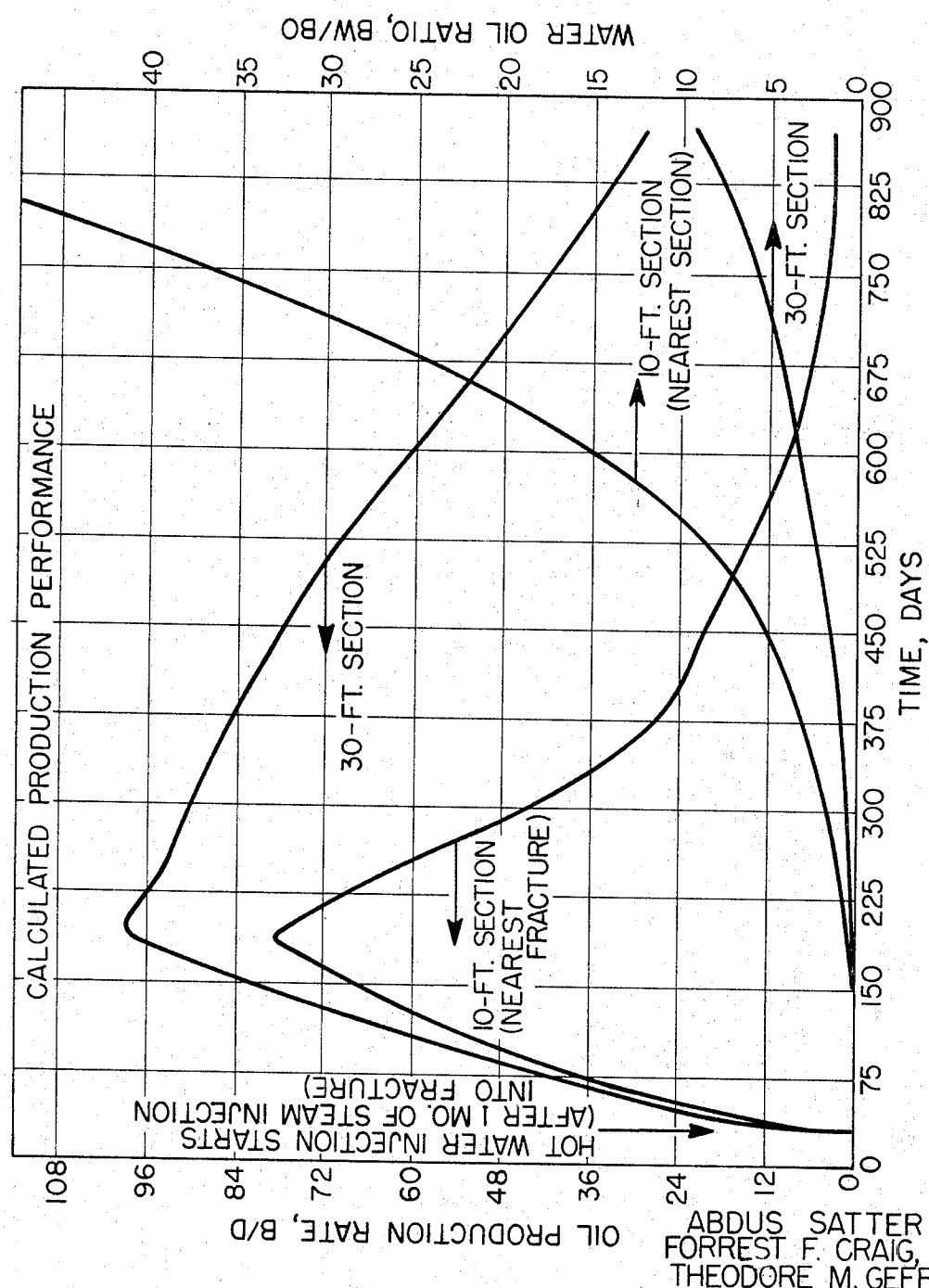


Fig. 2

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RECOVERY OF PETROLEUM BY THERMAL METHODS

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ABSTRACT OF THE DISCLOSURE

Horizontal fractures are made in nonpay sections such as shales, outside of or within the gross pay zone. Steam is injected through these fractures at a central well and condensed water is produced at the surrounding wells. After steam breakthrough, the steam injection rate is reduced with time to make sure that hot water essentially at the injected steam temperature will be produced, using only the latent heat of condensation of the injected steam at decreasing injection rates. A single well injection and production scheme may be used at the producing wells by utilizing the excess steam. The heated oil is also produced by injecting steam into the oil reservoir; altertimes the oil viscosity in centipoises at the original natively hot water may be used.

The present invention relates to a novel method for recovering petroleum from underground deposits thereof. More particularly, it is concerned with the production of petroleum from reservoirs of low mobility and which normally would be considered unsuitable for exploitation by conventional fluid injection recovery methods. As used in the present description the term "petroleum" is intended to include tars and viscous oils as well as high gravity, e.g., 40° API, crudes. The expression "low mobility reservoir" as used in the present description and claims is intended to mean a reservoir in which the flow capacity thereof in millidarcy feet is less than about 30 times the oil viscosity in centipoises at the original reservoir temperature.

Briefly, the process of our invention involves first fracturing a petroleum bearing reservoir of the type contemplated herein in accordance with well-known fracturing techniques. With reservoirs of such low mobility, water can ordinarily be used as the fracturing liquid. After the fractures are created, heat is supplied to the formation by injection of steam or hot water through the fractures. When the reservoir has thus been heated so as to render the oil, tar, etc., readily flowable, any of several recognized processes, including the continuation of steam injection, forward combustion, hot waterflooding, etc., may be employed to recover the oil from an offset producing well or wells.

It has previously been thought (see U.S. Patent 3,154,142) that the only way in which combustion can be conducted in reservoirs of low mobility was by means of reverse combustion, as taught by Morse in U.S. 2,793,696. Others have used the method of Morse in reservoirs of the aforesaid type as indicated by Campion et al. 3,174,544, to render formation fluids of low mobility sufficiently mobile to support forward combustion.

It is accordingly an object of our invention to provide a method by which oil, tar, or equivalent reservoirs having low fluid mobility can be subjected to forward combustion without previously using the reverse combustion step thereon. It is another object of our invention to provide a method for conditioning an oil bearing reservoir in such a way that the oxygen utilization during a subsequent combustion process is increased. It is still another object of our invention to provide a means by which heat losses to the surrounding formation during oil displacement by fluid injection into the oil bearing reservoir are substantially reduced. It is a further object of our invention to materially reduce the substantial pressure drop normally experienced when it is attempted to conduct forward combustion in a reservoir of initial low fluid mobility. It is another object of our invention to recover hydrocarbons from reservoirs of the aforesaid type by first forming one or more fractures or zones of relatively high permeability in or adjacent the oil bearing zone, thereafter injecting steam or a steam-water mixture into the fracture(s) until the temperature substantially throughout said zone is at least about 50° F. above its normal level, and then subjecting the reservoir while at this elevated temperature to a fluid injection process to recover oil of reduced viscosity from a producing well. The zones of higher permeability may be in the pay and/or nonpay sections, i.e., relatively impermeable zones such as shales, located adjacent or within the gross pay section.

In the drawings:

FIGURE 1 is a plot showing the distribution of heat over varying periods of time from a fracture in a reservoir subjected to the method of our invention.

FIGURE 2 shows the oil production rate and produced water-oil ratios for a 30-ft. pay section as well as the 10-ft. section of the pay nearest a fracture when using the process of our invention.

In carrying out an embodiment of our invention, a low mobility oil bearing reservoir penetrated by an injection well and a producing well is first fractured, either at some level in the pay zone or in a non-oil bearing zone located outside and/or within the gross pay zone. The fracturing operation in low permeability reservoirs as contemplated herein may be carried out with water. To produce such fractures, for example in a tar sand at a depth of about 1000 feet, pressures of the order of about 1200 to 1600 p.s.i. are generally needed. While these fractures or zones of relatively high permeability are not necessarily propped open in the usual way, we have observed that once they are formed, they can be reopened by the use of no more than about ¾ the pressure initially required. One of the practical advantages of these fractures or zones of high permeability thus created is that they reduce the pressure drop across the system, requiring lower injection pressures which in turn result in lower air injection costs. In the case of the tar sands, or similar unconsolidated oil bearing formations, we do not know that fractures are actually formed, but we have observed that the injectivity of such a formation is increased after being subjected to a fracture type operation. Thus, where water is used as the fracturing liquid, it is possible that these permeable zones or channels are formed by the high pressure water streams surging through the formation to remove some of the sand with them. For example, these channels can be extended readily from a central injection well to a number of surrounding (producing) wells or vice versa so that communication is established between the injection and production wells.

After the fracturing operation, steam, preferably about 80 percent quality steam, is injected through the more permeable zones formed by the fracturing operation. In the example just mentioned, the steam is preferably injected through the central well and the resulting condensate produced from the surrounding wells. Steam injection is preferably carried out at the full fracture or boiler capacity to realize the maximum rate of reservoir heating. Eventually—typically within one to four months,

depending on injection rate, steam temperature, and distance between wells—steam breakthrough occurs at the producing wells.

After steam breakthrough, the rate of heat dissipation (due predominantly to conduction) from the fractures into the surrounding formation decreases with the injection time since the thermal gradient around the fractures decreases with time. If steam is injected at the original rate, the quality of steam produced increases with time and unnecessary loss of the injected heat results. We therefore prefer that the steam injection rate be reduced with time, making sure that hot water essentially at the injected steam temperature is produced. Otherwise stated, only the latent heat of condensation of the injected steam should be used to provide heat to the reservoir at decreasing injection rates. Injection of steam through the fracture is continued until the major portion of the reservoir is heated at least to a level such that the original oil viscosity is substantially reduced and the resulting hot thinned-out oil can be displaced efficiently by any of several conventional recovery processes. Ordinarily, a temperature rise of at least about 50° F. throughout the reservoir is considered adequate to bring about the desired reduction in viscosity. This phase of steam injection may last several months, depending mainly on the oil zone thickness, the area involved, and the injected steam temperature.

While the reservoir is being heated as outlined above, the boiler may be operated at its full capacity for huff and puff steam stimulation of the producing wells by utilizing the excess steam—over and above that required for injection into the fractures—from the boiler. In a large-scale operation involving more than one flood pattern, the excess steam may be used in several patterns.

When the reservoir oil is reduced in viscosity to the desired value, steam injection into the fractures can be terminated and other fluids injected as will be discussed in greater detail below. However, if desired, steam injection can be continued after the desired reduction in oil viscosity is reached, to displace oil towards the producing wells. Since the original oil viscosity is reduced substantially, the steam can be injected more easily than ordinarily could be achieved by injecting steam into cold reservoir without preconditioning as outlined above. For example, such steam injection pressures may range from about 200 to about 2500 p.s.i. For the cases illustrated below, the formations surrounding the oil reservoir are at elevated temperatures, therefore heat losses during steam injection into the oil bearing zone are substantially reduced.

As an alternative to steam injection, after the viscosity of the oil has been reduced to the desired level, steam from the boiler may be used to generate hot water at the steam temperature by mixing steam and a predetermined amount of cold water. The resulting hot water may then be introduced into the oil reservoir at the injection well to displace oil toward the producing wells. Hot water displacement may not be as efficient as the steam displacement of oil. However, in a situation where no great advantage may be gained in raising the entire oil reservoir to the very high steam temperature, hot water can be generated at a lower temperature than the steam temperature and then injected into the oil reservoir. In this case the flood-out time of the reservoir may be substantially reduced.

Other fluid injection methods for displacing and recovering the oil, tar or bitumen of reduced viscosity, resulting from steam injection through the zones or channels of higher permeability, include subjecting the heated oil pay to one of the recognized recovery methods, such as waterflooding, gas injection, forward combustion, a combination of forward combustion and water-flooding, etc. Conditions employed in forward combustion are well known to the art and are discussed in some detail in U.S. 3,174,544, mentioned above, while the procedure for carrying out forward combustion and waterflooding is taught in Craig et al. U.S. 3,196,945. Thinning of the oil between injection and production wells provides a high mobility zone through which a driving fluid and driven hydrocarbon can move through the pay and be recovered at the production wells. A further benefit of conditioning the oil pay by means of steam injection in accordance with our invention is that the higher than natural temperature prevailing in the reservoir provides for higher oxygen consumption efficiency when subsequently applying a recovery method such as underground combustion. In cases where the fracture is in the pay itself, the injection pressure required in the subsequent oil displacement phase of our process is less than the original fracturing pressure.

In a practical application of our invention using, for example, a 5-acre, 5-spot pattern where a fracture was formed 5 feet below the oil zone in a shale streak, the temperature of the shale-oil zone interface was about 312° F. after six months' steam injection, compared to 90° F. at the top of the pay which was 35 feet from the fracture. Heating through a number of equally spaced fractures raises the oil temperature more evenly, however. Over a 2½-year period, 63,000 barrels of oil, i.e., 36 percent of the original oil in place, was recovered. About 41 percent of recoverable oil can be produced from the 10-ft. pay section (⅓ the thickness of the total pay under consideration) close to the fracture, compared to 35 percent from the middle 10-ft. pay zone and 24 percent from the top 10 feet of the pay. The difference in recovery efficiency from the different sections of the pay is related to the vertical temperature distribution in the pay. As a matter of interest, conventional waterflood recovery for the same formation was calculated to be about 6 percent. Thus, it is seen that the process of our invention offers a striking advantage over conventional waterflooding techniques as applied to heavy oil deposits.

In connection with the above case, we refer now to FIGURE 1 which shows that conduction heating from a single fracture is not vertically uniform. For example, at the end of one year of steam injection the temperature at the shale-oil zone interface is 330° F., compared to 105° F. at a vertical distance of 45 feet from the fracture. According to the process of our invention and using a number of evenly spaced fractures, the oil reservoir can be more evenly heated. With more uniform temperature distribution in the oil zone, the displacement of the reservoir oil by the subsequent oil recovery operation can be more efficient. It will also be noted that the rate of temperature increase at a given position decreases with injection time and the temperature tends to stabilize. Thus, a limited injection time is involved beyond which the conduction heating of the pay zone from the single fracture is ineffective. We therefore prefer that conduction heating from the fractures be terminated at the end of the optimum injection time as may be determined by reference to FIGURE 1.

FIGURE 2 shows oil production rate and the produced water-oil ratios for the entire 30 ft. section of the pay as well as the 10-ft. pay section nearest the fracture. The peak oil production rate from the 30-ft. pay zone is shown to be 99 BOPD after 200 days of project life, compared to 78 BOPD from the 10-ft. section at about the same time. In the case of the 10-ft. section, however, the production rate declines rapidly and at the end of 2½ years, the rate is only 3 BOPD, compared to 29 BOPD from the entire pay. The sections of the pay closer to the fracture respond faster to the oil recovery mechanism involved in the process of our invention, but they also water-out faster than sections of the formation farther away from the fracture. At the end of the life of the project, the water-oil ratio was 9:1, although such ratio for the lower ⅓ of the pay was in excess of 50:1, while the bottom 1-ft. section of the pay produced substantially 100 percent water at the end of the project.

In carrying out an operation such as that discussed

immediately above, the average steam injection rate into the fracture over the 2½-year life of the project was 8300 lbs./hour of 80 percent quality steam at 200 p.s.i.a. and 382° F. It might be pointed out, however, that after steam breakthrough, the steam injection rate decreased drastically, e.g., to about 5000 lbs./hour after 2½ years. The decrease in injection rate is due to the decrease in thermal gradient time around the fracture. The average hot water injection rate into the pay was about 200 bbls./day, i.e., 3000 lbs./hour. Heat balance calculations show that about two 5-acre, 5-spot patterns may be operated by using a 20,000 lbs./hour boiler which is a conventional sized unit. Excess steam over that required for the injection operation could be mixed with about 3000 lbs./hour of cold water to generate hot water at steam temperature where hot water is to be used as the driving fluid.

An embodiment of our invention in which in situ combustion is employed after the temperature of the petroleum deposit has been increased to the extent of at least 50° F. is illustrated in the following example:

Example

Athabasca tar sand (306.25 pounds) containing 15 weight percent tar was packed into a combustion cell 12 inches in diameter and 4 feet long. In the middle of this cylinder of tar was a crack ¼ inch thick by 8 inches wide, filled with 20–40 mesh flint-shot sand to simulate a zone or channel of relatively high permeability. Steam at 150 p.s.i.g. was injected for about 1½ hours to heat the tar sand to a temperature ranging from about 355° F. at the outlet to about 365° F. at the inlet. Thereafter air injection at the rate of 23 s.c.f.h. was initiated. At the inlet the temperature dropped 20°–30° F. but at the outlet it decreased only about 1° F. About two hours after the start of air injection the temperature of that portion of the tar sand between 3.5 and 4 feet from the inlet end of the cell increased 5°–12° F. Thereafter a temperature increase was also noticed in portions of the cell closer to the inlet. The highest temperature area tended to move in the direction of the air inlet. After the combustion front had reached a point approximately 3 feet from the inlet, the front reversed its path and traveled in the same direction as the air flow. While the run was in progress, melted tar and water were collected. The run was halted prematurely due to a ruptured valve in the product line. However, it clearly demonstrated that hydrocarbon bearing formations can be brought, by steam injection, to a temperature sufficient to cause a portion of the hydrocarbons therein to burn when subsequently contacted with air at such temperature, resulting in a flow of hot, thinned oil through the formation to a producing well. During the course of the run the pressure within the cell averaged 714 p.s.i.g. and oxygen consumption during the last six hours of the run was 99.6 percent, indicating a very efficient combustion process. The observed peak temperature was 1234° F. with the average during the combustion portion of the run being about 1080° F.

It should be pointed out that by the process of our invention, as illustrated in the above example, combustion can be initiated without the use of a separate ignition step. This is not only advantageous because of the savings in time but is desirable since it avoids the use of a rather costly and sometimes dangerous procedure.

It will be apparent from the foregoing description that we have developed a method of thermal recovery having wide application in hydrocarbon bearing reservoirs of low permeability. As contemplated by our invention, such reservoirs are not necessarily limited to those having high viscosity oils, i.e., not more than about 25 API gravity, or tar, but on the contrary, our process is equally applicable to the less viscous, higher gravity, e.g., 40° API, oils present in reservoirs of low permeability.

We claim:

1. In a method for recovering petroleum from an underground oil bearing formation of low mobility penetrated by an injection well and a producing well, a non-oil bearing zone being adjacent said formation, the improvement which comprises subjecting said zone to fluid pressures sufficiently high to create a channel of relatively high mobility in close proximity to said oil bearing formation; thereafter injecting steam at a temperature of at least about 300° F. into said channel and continuing steam injection until the temperature of a major portion of said petroleum has been increased to at least about 50° F. above the normal reservoir temperature; and thereafter, while said petroleum is in a heated condition, subjecting said deposit to a conventional fluid injection recovery method.

2. The method of claim **1** in which hot water at a temperature of at least about 300° F. is the fluid employed in said recovery method.

3. The method of claim **2** in which the petroleum is a bituminous tar.

4. The method of claim **2** in which the petroleum involved is a viscous oil having an API gravity of not more than about 25°.

5. The method of claim **1** in which steam at at least about 300° F. is employed in said recovery method.

6. The method of claim **5** in which the petroleum involved is a bituminous tar.

7. The method of claim **5** in which the petroleum involved is a viscous oil having an API gravity of not more than about 25°.

8. The method of claim **1** in which the conventional fluid injection recovery method employed is in situ combustion.

9. The method of claim **8** in which no separate ignition step is employed.

10. The method of claim **8** in which the petroleum involved is a viscous oil having an API gravity of not more than about 25°.

11. The method of claim **8** in which the petroleum involved is a bituminous tar.

12. The method of claim **1** in which the petroleum involved is a bituminous tar.

13. The method of claim **1** in which the petroleum involved is a viscous oil having an API gravity of not more than about 25°.

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STEPHEN J. NOVOSAD, *Primary Examiner.*

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,375,870 April 2, 1968

Abdus Satter et al.

It is certified that error appears in the above identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 25, cancel "times the oil viscosity in centipoises at the original".

Signed and sealed this 5th day of August 1969.

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents