United States Patent Office

3,115,928

Patented Dec. 31, 1963

1

2

3,115,928

HEAVY OIL RECOVERY

Frank E. Campion and Eugene D. Glass, Tulsa, Okla., and Richard A. Morse, Pittsburgh, Pa., assignors to Pan American Petroleum Corporation, Tulsa, Okla., a corporation of Delaware

No Drawing. Filed Aug. 14, 1959, Ser. No. 833,694
6 Claims. (Cl. 166—11)

This invention relates to the recovery of oil, tar, or similar carbonaceous substances from the underground strata in which they occur and is directed particularly to the recovery of heavy oils, tars, and similar carbonaceous substances by applying heat to them. More specifically, the invention is directed to heavy-oil recovery by reservoir heating wherein the heat is generated by combustion or oxidation within the deposit or the reservoir stratum itself.

The present application is a continuation-in-part of our application Serial Number 525,284, filed July 29, 1955, which issued on August 25, 1959 as U.S. Patent Number 2,901,043.

As is evident from the growing number of publications and patents, underground combustion wherein heat is generated by in situ combustion within an oil or tar-producing stratum, is assuming increasing importance as a means of improving heavy-oil recovery. Especially are such processes applicable to the recovery of heavy oils, tars, and like carbonaceous substances which are permeable to gas flow but are relatively nonflowable under ordinary reservoir conditions and are, therefore, not recoverable by the usual methods of oil recovery. Such substances, however, may become recoverable by ordinary methods when sufficiently heated.

One important class of underground combustion processes is that wherein the flow of fluids through the reservoir stratum and the propagation of a zone of combustion therein take place in opposite or countercurrent directions. Such processes are sometimes referred to simply as inverse or reverse combustion processes. In the usual reverse-combustion process, however, substantially all of the in-place oil is contacted by the combustion zone and thereby subjected to the high temperature of said zone, which for certain oils may be either unnecessary for their recovery or undesirable because of the cracking and/or oxidation products thereby produced.

This is not necessarily true of one member of the class of reverse combustion processes which uses naturally occurring or artificially created fracture systems in an underground reservoir stratum. By substantially confining the combustion to the fractures, in the manner described in our above-mentioned patent, a limited amount of heating of the in-place oil is done. The oil is therefore less drastically modified by cracking and other thermal processes than is true of reverse combustion generally in the absence of fractures.

It is a primary object of this invention to improve still further the recovery of heavy oils, tars, and like carbonaceous substances by underground reverse combustion utilizing fractures, wherein the reverse combustion is either the primary recovery means or is a heat-providing adjunct to recovery by other mechanisms or processes. It is a further object of the present invention to improve the efficiency of recovery of heavy oils, tars, and the like, by using underground reverse combustion in fractures with limitation of the amount of in-place heating and with improved recovery of the heated oil. A still further object of the invention is to provide a substantial degree of control of the speed of propagation and the temperature of an underground, reverse-propagating combustion zone in an oil-recovery process. Other and further objects uses and advantages of the invention will become apparent as the description proceeds.

Briefly stated, we have found that important improvements in underground reverse-combustion processes in fractures result when a low-gas-pressure, heavy-oil producing formation, after first being fractured, is subjected to gas injection so as to reach an elevated static pressure, before ignition of the reverse-combustion zone is done. Ignition of a zone of combustion is then accomplished at the bore of the output well, and this combustion is supported and reverse-propagated by continued gas injection, while holding back pressure at the output well.

One important effect of this preliminary gas-injection step, followed by holding back pressure on the output well while combustion takes place, is that described in our above-mentioned patent wherein the injected gases permeate the reservoir stratum over a wide area and to some extent go into solution in the oil in place. Typically, this results in some reduction of the viscosity of the in-place oil, which viscosity is by heating still further and markedly reduced to a final value substantially lower than it otherwise might be. Furthermore, the breakout of solution gas and the expansion of non-dissolved gas bubbles in that part of the reservoir heated by the passage of the reverse-propagating combustion zone, help to drive the warmed heavy oil to the producing well. As is explained in our above-mentioned patent, gradually reducing the back pressure at the producing well during the combustion operation tends to accentuate this effect.

By thus initiating the combustion at a relatively high level of static formation pressure and somewhat lowering this pressure during the ensuing recovery process, a substantial increase in the percentage of in-place oil recovered often occurs, especially in the case of low-gas-saturation oils which can absorb substantial amounts of the injected gas. The energy added to the reservoir hydrocarbons by thus increasing the initial static reservoir gas pressure and saturation, is largely recovered upon the breakout of this gas and its driving effect upon the hydrocarbons which take place upon the subsequent occurrence of heating. This is generally a more efficient way of utilizing the driving energy of gas in the recovery of heavy hydrocarbons than the mere circulation of the gas through the formation from an input to an output well to entrain or drive the heavy hydrocarbons through the rock pore spaces by gas flow alone.

An additional important effect of injecting gas before ignition of a reverse-propagating combustion zone is that, when the zone is subsequently ignited and propagation starts while holding back pressure at the output well, the peak temperature of the combustion zone is substantially lower, and its propagation rate is substantially greater, than they otherwise would be. Thus, for initially low-gas-pressure reservoirs, a preliminary step of gas injection followed by the holding of back pressure during and following ignition at the output well, provides substantial control over the temperature conditions within the reverse-propagating combustion zone. Operation at an elevated pressure thus constitutes an additional way of limiting the amount of heat imparted to the oil in place over and above that due to substantially confining the combustion to fractures.

In accordance with a preferred embodiment of our invention, a low-gas-pressure reservoir stratum is first fractured by extending one or more horizontal fractures between an input and an output well, and gas is injected through one or both walls, to travel easily along these fractures and permeate the reservoir formation between the fractures and around the two wells. When the initially low reservoir gas pressure has been raised to a level substantially above atmospheric, combustion is then initiated at the bore of the output well and is reverse-propagated principally through the fractures by injecting oxygen-containing gas into the input well and through the formation and fractures to the combustion zone. A substantial back pressure at the output well, which places the combustion zone within the formation and/or fractures under substantially superatmospheric pressure, is held for part or all of the time the reverse propagation continues.

As to the nature of the pre-injected gas, it can be any one or a mixture of several gases such as methane, natural gas, or such gases including vapors of heavier hydrocarbons. In this case, substantial solution of the hydrocarbon gas or gases takes place in the heavy in-place oil or tar, with some lowering of its viscosity as a direct result. Alternatively, the pre-injected gas can be one which is relatively insoluble in the in-place oil or tar, such as air, combustion-product gases, carbon dioxide, and the like, in which case, although less gas goes into solution in the oil, and less direct viscosity reduction occurs on that account, the injected gas is still present and available throughout the reservoir to assist in supporting the combustion zone and/or in creating a gas-pressure drive of the heated oil toward the producing well when the combustion zone passes by. Obviously, if the pre-injected gas is a mixture of oxidizing and fuel gases, care must be exercised to avoid explosive mixtures in the input well bore.

As to the amount of gas to be pre-injected, or the pressure level to which the reservoir pressure is to be raised, it may also be varied within relatively widely spaced limits which depend upon a number of factors such as the initial reservoir gas pressure, gas solubility in and the nature of the oil in place, the desired degree of lowering of combustion-zone temperature and/or of increasing the propagation rate, and the like. As a guide to the approximate magnitude of the effects produced by gas pre-injection and initiation of the combustion zone under superatmospheric pressure, while holding back pressure on the output well for at least a substantial part of a recovery process, the results of the following experiments are cited.

Examples

A laboratory combustion cell comprising a central tube surrounded by heat-insulating materials and provided with thermocouples for observing the temperature at a plurality of spaced points within and along the tube, was filled with Athabasca tar sand. For each of several tests, the conditions of combustion of the cell were substantially duplicated except for the pressure maintained therein by holding back pressure at the outlet end of the cell. For one pair of such tests, air was injected at the rate of about 50 standard cubic feet per hour per square foot of area of the reverse-combustion zone. Combustion was initiated at the outlet end of the cell and caused to propagate in a reverse direction through the cell toward the inlet. For one of these two tests, the back pressure at the outlet end of the cell was held within a range of 0 to 10 pounds per square inch above atmospheric, while in the other test the back pressure was maintained at an average value of about 250 pounds per square inch above atmospheric. For the low value of back pressure, the average velocity of the reverse-combustion zone propagation was about .12 foot per hour, and the average temperature of the combustion zone as it passed the various thermocouples was about 800° F. For the higher back pressure, the average combustion-zone velocity along the cell was about .44 foot per hour, and the corresponding average temperature was about 600° F.

These results were checked by another pair of tests at the same two different pressure levels and at a slightly different air rate, namely, about 60 standard cubic feet of air per hour per square foot of combustion zone area. This pair of tests gave propagation velocities for the combustion zone of .17 and .45 foot per hour and temperatures of about 870° F. and 650° F., respectively, for the low and the high values of back pressure.

A still further pair of tests at the slightly reduced air rate of about 45 standard cubic feet per hour per square foot of combustion zone area gave, with substantially zero back pressure, a temperature averaging about 810° F. and a velocity of about .14 foot per hour, while at 250 pounds per square inch gauge pressure, the corresponding temperature and velocity were about 610° F. and about .40 foot per hour.

Although all of these pairs of tests were run using Athabasca tar sand saturated with Athabasca tar, they are truly representative of other tests performed on several different heavy oils and tars, since substantially the same combustion-zone temperatures and propagation velocities were obtained for all oils. This is a characteristic of reverse-combustion processes generally which distinguishes them from forward-combustion processes, which vary little with changes in applied pressure and a great deal with the varying nature of the in-place oil.

It is noteworthy also that, with high pressure and correspondingly low temperature and high combustion-zone velocity, much less of the in-place oil flows to the producing well and is recovered during the reverse-propogating phase of the combustion operation than is true for ordinary reverse combustion processes conducted under conditions of high temperature and without fractures. However, the reverse-combustion propagation leaves the oil or tar in the reservoir formation in a heated, relatively low-viscosity condition such that it can be recovered by other recovery processes, such as a gas or liquid pressure drive, by a forwardly propagating combustion process, or by some combination of these and other well-known recovery means.

As to how the back pressure is maintained at the output well, it may be held constant, or it may be lowered continuously or step-wise at intervals during the recovery process. Certain advantages accrue to each type of operation, and it is of some importance to understand what these are in order to choose which type of operation is preferable for a given recovery operation.

It should be noted that the primary effect of the output-well back pressure is to place the combustion zone itself under an elevated pressure. This establishes a definite combustion-zone temperature and reverse-propagation rate, which do not vary appreciably unless the pressure at the combustion zone changes. At the time of ignition in the output well bore, the combustion-zone pressure is, of course, the same as the back pressure in the output well bore. As the combustion zone moves away from the output well through the fractures however, the pressure drop of the flow through the intervening space between the combustion zone and the output well bore adds to the maintained back pressure in establishing the actual pressure at the combustion zone itself. Therefore, in order to maintain a constant pressure at the position of the combustion zone, it is necessary to decrease the back pressure sufficiently to offset the effect of the rising flow resistance in the fractured formation between the combustion zone and the bore of the output well. By thus maintaining a constant pressure on the combustion zone itself, the operating conditions therein and the propagation velocity, as well as the effect produced on the in-place oil actually contacted by the combustion zone, remain substantially constant and predictable, assuming that other variables such as the composition and injection rate of the input gas stream are properly controlled.

On the other hand, by more rapidly lowering the pressure continuously or step-wise at intervals throughout the recovery process, the action of the injected combustion-supporting gas in helping to drive the heated oil to the producing well can be augmented by the breakout of dissolved gas and the expansion of non-dissolved gas bubbles.

Furthermore, lowering the pressure at the combustion zone results in an increasing temperature as the operation proceeds. This produces more cracking of the oil in place adjacent the fractures and thus achieves an additional viscosity reduction in this manner, over and above that produced by the heat alone. The light-hydrocarbon cracking products produced then aid somewhat in the recovery of the heavy oil by creating a type of inplace miscible-fluid drive which, as is well-known, is more efficient than non-miscible liquids or gases in displacing oil from the reservoir pore spaces.

Another advantage of a continuous or step-wise reduction in back pressure is that the accompanying temperature rise in part tends to offset the increasing loss of heat from the expanding heated zone which remains between the zone of combustion and the output well bore, and thus to a large extent retains this zone at a constant elevated temperature.

From the foregoing it will be understood that manipulation or control of the pressure conditions at the location of an underground reverse-propagating zone constitutes a sensitive method of controlling the operation of the combustion process. This is entirely unlike forward-combustion processes where the temperature and the rate of propagation of the combustion zone are substantially independent of the applied pressure but vary more in accordance with the nature of the in-place oil. In the reverse-combustion process the nature of the in-place oil is of less importance, and the pressure exerts a profound effect on the operation of the process, in that the percentage of oil consumed and the amount of heat generated can be varied extensively by relatively small changes in the pressure conditions. Thus, the over-all efficiency of a reverse-combustion operation can be readily controlled by the back pressure maintained at the output well, so that the recovery efficiency in terms of the ratio of produced oil to the volume of injected air is a maximum.

The above examples and discussion should not be interpreted to mean that reverse-combustion conditions cannot be controlled by other means than manipulating the effective pressure at the combustion zone. Such control by regulation of pressure is an addition to the control measures taught in our Patent 2,901,043, such as oxygen concentration and/or rate per unit area or length of combustion zone, proportion of inert fluids, and the like. By combining its unusual sensitivity to pressure with other control measures, reverse combustion as a process of in situ heating and/or heavy oil recovery is applicable to a wide range of reservoir conditions and oil properties.

While we have thus described our invention in terms of the foregoing embodiment and specific details, it is to be understood that other and further modifications will be apparent to those skilled in the art. The scope of the invention therefore should not be considered as limited to the specific details set forth, but it is properly to be ascertained by reference to the appended claims.

We claim:

1. In a method of recovering a high-viscosity oil from an underground low-gas-pressure producing formation in which it occurs, wherein heat is generated by combustion within said formation, which formation is penerated by at least two spaced wells, one of said wells being an input and the other of said wells being an output well, the improvement which comprises the steps of initially providing at least one generally horizontal fracture extending continuously through said formation between said well, said fracture having a gas-flow capacity which is large compared to the gas-flow capacity of said formation without said fracture, initially injecting gas through at least one of said wells into said formation to flow through said fracture and permeate said formation throughout the space between said wells until the gas pressure in said space reaches a level substantially above atmospheric pressure, those of said wells through which gas is not injected being maintained closed-in during said injecting step, thereafter heating said formation at the bore of said output well to the combustion-supporting temperature of the oil therein, while supplying thereto a combustion-supporting gas to initiate a combustion zone in said fracture at the bore of said output well, injecting a combustion-supporting gas through said input well to flow primarily through said fracture to support said combustion to propagate a zone of combustion chiefly along said fracture back toward said input well, holding back pressure on said output well to maintain said pressure level for a substantial part of the time of propagation of said zone through said fracture toward said input well, and recovering from said output well the oil which flows thereto from said formation.

2. The improvement in accordance with claim 1 wherein said fracture-providing step comprises forming a plurality of generally horizontal fractures extending continuously through said formation between said wells with an approximately uniform vertical spacing of from about five to twenty feet between adjacent ones of said fractures.

3. The improvement in accordance with claim 1 wherein said back pressure-holding step comprises reducing said back pressure at about the same rate as the pressure drop due to the flow resistance from said combustion zone to said output well tends to increase.

4. The improvement in accordance with claim 1 wherein said back pressure-holding step comprises reducing said back pressure at a substantially greater rate than the pressure drop due to the flow resistance from said combustion zone to said output well tends to increase.

5. The improvement in accordance with claim 1 wherein said initial gas-injecting step comprises injecting a gas mixture which includes a substantial portion of natural gas having a substantial solubility in said high-viscosity oil.

6. The improvement in accordance with claim 1 wherein said initial gas-injecting step comprises injecting gas until the pressure in said space is at least about 250 pounds per square inch above atmospheric pressure.

References Cited in the file of this patent

UNITED STATES PATENTS

2,642,943	Smith	June 23, 1953
2,777,679	Ljungstrom	Jan. 15, 1957
2,917,112	Trantham et al.	Dec. 15, 1959
2,917,296	Prentiss	Dec. 15, 1959

FOREIGN PATENTS

481,151	Canada	Feb. 12, 1952