

UNITED STATES PATENT OFFICE

2,382,471

METHOD OF RECOVERING HYDROCARBONS

Frederick E. Frey, Bartlesville, Okla., assignor to
Phillips Petroleum Company, a corporation of
Delaware

No Drawing. Application March 3, 1941,
Serial No. 381,597

10 Claims. (Cl. 166—21)

This invention relates to a method of recovering hydrocarbons from an underground reservoir and is especially applicable to the secondary recovery of hydrocarbons from oil-bearing formations. The method of the present invention contemplates the inception and maintenance of flameless combustion within a hydrocarbon-bearing formation for the purpose of developing temperatures of sufficient magnitude to effect distillation and/or cracking of carbonaceous material and to drive thermally volatilized portions of the material from a thermally treated region to another location whence it can be readily produced to the surface of the ground.

The recovery of oil from a subsurface formation may be accomplished by several means. The oil may be initially produced by natural means, such as gas or rock pressure, natural water drive, or solution gas pressure. When these natural forces are insufficient to cause the oil to flow from producing wells at an economical rate, the oil may be pumped or raised by any desired known method. When pumping methods can no longer produce oil from a particular formation at an economical rate, additional oil may be recovered by the employment of secondary recovery methods, for example, by water-flooding or repressuring the partially depleted sands. These methods involve the injection of water, gas, air, or a combination of these into the formation through one or more input wells and the withdrawal of oil through one or more output or producing wells.

The instant invention, while it relates to secondary recovery in the sense that it is concerned with the production of hydrocarbons from a formation that has been substantially depleted of natural energy for moving the same through a formation, nevertheless goes much further than present-day methods of increasing the ultimate recovery of hydrocarbons from a given oil-bearing strata. One important aspect of this invention resides in the fact that it is not dependent on an adequate supply of fluid driving medium, as required for the successful operation of usual secondary recovery methods, for my invention utilizes any free oxygen-containing gas, such as air, to initiate and maintain combustion in a formation for the purposes indicated. Furthermore, the practice of my invention converts hydrocarbons, while they are in the formation, to more desirable forms and thereby reduces and in some cases eliminates the need for treating or processing the fluid after it reaches the surface of the ground. As will be evident from a perusal of the detailed discussion that appears further along,

my invention affords a number of distinct and highly desirable advantages over known methods of recovering hydrocarbons.

It is therefore the primary object of this invention to recover hydrocarbons from subsurface strata.

Another object of this invention is to provide a method of increasing the ultimate recovery of hydrocarbons from hydrocarbon fluid-bearing formations.

A further object of this invention is to effect distillation and/or cracking of hydrocarbons in their natural environment.

A still further object is to effect melting and flow of solidified waxy deposits.

These and additional objects and advantages will be readily apparent to persons skilled in the art during the course of the following description, which, by way of example only, is directed to the recovery of hydrocarbons from oil-bearing formations.

The basic concept of my invention, as applied to the recovery of hydrocarbons from an oil-bearing formation, contemplates the introduction of air, oxygen enriched air, or any other suitable free oxygen-containing gas into the oil-bearing formation by pumping the same through one or more "input" wells. Assuming that air is used, flameless or non-flame oxidation is initiated and maintained in the formation to thereby heat the oil in the vicinity of the input well. It has been proposed to generate a flame at the bottom of the well and utilize the developed heat to decompose carbonaceous matter, but experience has shown that this technique is likely to seriously impair or completely destroy the perviousness of the formation at the point of application. On the other hand, controlled, flameless combustion will accomplish the desired results without appreciable damage to the formation. Considering an input well as the center of a hot zone, it will be apparent that this zone progressively increases in radius through the oxidation of relatively non-volatile carbonaceous material encountered, the burned out portion of the zone sufficing to preheat air passing outwardly to regions still unacted upon. Oil in the hot zone which is thus created is distilled and/or cracked, depending on the composition of the oil in the formation and the temperature and pressure within the zone. Hydrocarbon fluid in the formation, together with nitrogen and oxides of carbon resulting from the combustion, are moved through the formation to one or more "output" wells from

whence they are transmitted to the surface of the ground.

The most favorable conditions for the practice of my invention usually occur where a minimum of 250 pounds per square inch total pressure can be developed without an impracticably large flow of free oxygen-containing gas, where bottom hole temperatures are sufficiently high to initiate oxidation, and where excessive amounts of water do not exist in the formation. These conditions do not always occur, however, and it is therefore essential that the procedure be modified, depending on existing conditions in individual situations. More often, a pressure of 50 pounds per square inch, or even less, will be encountered; and, in a pervious formation or one with pervious zones distributed in a less pervious formation, the development of pressure by the introduction of gas to effect cracking or distillation will not be great. Consequently, means for supplying a proper gas at elevated temperatures to the formation may be necessary in order to initiate, and sometimes sustain, temperatures high enough for the purposes indicated, and it is a part of my invention to provide means for so doing.

Oxidation of heavy hydrocarbons will usually proceed without the development of flame, but with the development of temperature under mixed phase conditions. Where the oxygen is in the range of 50 to 200 pounds per square inch partial pressure or higher, the reaction generally requires a temperature of 350° F. or higher to start, after which the reaction may be successfully maintained within the temperature range of 350 to 600° F. The temperature required to initiate sufficiently rapid oxidation to bring about the necessary temperature rise is extremely variable, depending on the presence of autocatalytic materials. In some instances, a temperature as low as 200° F. suffices to initiate oxidation to produce the necessary temperature rise. Temperatures at and above this level frequently occur in deep wells. Many shallow formations exist, however, where secondary recovery is desirable, yet temperature of 120° F., or lower prevail.

Once oxidation is initiated, it will be automatically self-sustaining due to the temperature development in a particular zone. There are instances, however, where it may be difficult to bring about spontaneous oxidation. Such is the case where high perviousness of a formation and a low existing pressure therein necessitate the application of pressure in well bottoms that are below 50 pounds per square inch partial pressure of oxygen. In such instances, and in instances where reaction sets in with difficulty at higher applied pressures, there are certain reaction initiating means which may be applied advantageously. For example, the air or other free oxygen-containing gas that is forced into a formation through an input well may be admixed with certain substances, including water gas, or carbon monoxide. Ammonia or hydrogen may be used, but because of their cost may best be applied to aid in initiating the action of a combustion catalyst to be later described. This mixture is passed through a mass of suitable catalyst in the bottom of the well in order to initiate oxidation of these materials by oxygen at ordinary or slightly elevated temperatures. Various catalysts may be employed, of which many are known, including those containing the materials of the iron group, preferably in pyrophoric condition. The particular catalyst employed will depend largely upon conditions in a particular producing hori-

zon. One catalyst which is well suited for the purposes of this invention is Hopcalite. A free oxygen-containing gas which is admixed with carbon monoxide will, upon coming in contact with Hopcalite in the bottom of the well bore, initiate combustion at ordinary temperatures. By properly controlling the proportions of combustible matter and free oxygen-containing gas, the temperature of the gas on passing through the catalyst in a burned condition can be regulated and maintained below flame temperature for such time as it is essential to develop a sufficiently hot zone in the formation to sustain regular oxidation, whereupon the addition of combustible matter to the free oxygen-containing gas may be discontinued and free oxygen-containing gas alone is injected into the formation. By suitably regulating the proportions of air and combustible gas and flue gas, if desired, both temperature and any desired excess of unconsumed oxygen may be maintained. There are cases in which it is desirable to continue the use of the combustible matter after the initial period in order to maintain satisfactory operation. The above described combustion is thus controllable to avoid destruction of equipment or perviousness of the formation at the foot of the well.

The use of reasonably dry producer gas is recommended where it is important that water formation resulting from the practice of my invention be maintained at a minimum.

While the instant invention comprises the several steps and the relation of one or more of such steps to each of the other enumerated steps, it is to be clearly understood that various changes in the method of procedure may be resorted to without departing from the spirit of the invention, and further that the theories set forth, although believed to be accurate, are not to be considered as the sole basis of the operativeness of this invention, but that this method does operate successfully and effectively whether or not upon the principles described herein, this invention to be limited only by the appended claims. Minor changes to make a preferred adaptation to any particular situation may be readily made by one skilled in the art, as trial may indicate.

I claim:

1. In a method of recovering hydrocarbons from a hydrocarbon oil-bearing formation which is penetrated by an input well and an output well, the steps comprising transmitting free oxygen-containing gas into the formation through the input well, initiating and maintaining flameless oxidation of carbonaceous material in the formation to heat the oil therein and effect distillation of relatively low boiling point components of the oil, and withdrawing distilled components of the oil through the output well.

2. In a method of recovering hydrocarbons from a hydrocarbon oil-bearing formation which is penetrated by an input well and an output well, the steps comprising transmitting free oxygen-containing gas into the formation through the input well, initiating and maintaining flameless oxidation of carbonaceous material in the formation to heat the oil therein and effect cracking of relatively high molecular weight hydrocarbons, and withdrawing cracked components of the oil through the output well.

3. In a method of recovering hydrocarbons from a hydrocarbon oil-bearing formation which is penetrated by an input well and an output well, the steps comprising transmitting free oxygen-containing gas into the formation through the

input well, initiating and maintaining flameless oxidation of carbonaceous material in the formation to effect distillation of relatively low boiling point components of the oil and cracking of relatively high molecular weight components of the oil, and withdrawing hydrocarbon fluid through the output well.

4. In a method of recovering hydrocarbons from a hydrocarbon oil-bearing formation which is penetrated by an input well and an output well, the steps comprising introducing free oxygen-containing gas into the input well, transmitting the free oxygen-containing gas through a suitable catalyst that is disposed in the portion of the input well which penetrates the oil-bearing formation to initiate flameless oxidation of carbonaceous material in the formation, and withdrawing hydrocarbon fluid through the output well.

5. In a method of recovering hydrocarbons from a hydrocarbon oil-bearing formation which is penetrated by an input well and an output well, the steps comprising introducing a combustible fluid including free oxygen into the input well, contacting the combustible fluid with a suitable catalyst in the portion of the input well that penetrates the oil-bearing formation to initiate flameless oxidation in the formation, and withdrawing hydrocarbon fluid through the output well.

6. In a method of recovering hydrocarbons from a hydrocarbon oil-bearing formation which is penetrated by an input well and an output well, the steps comprising introducing a combustible fluid including free oxygen into the input well, contacting the combustible fluid with a suitable catalyst of the iron group in the portion of the input well that penetrates the oil-bearing formation to initiate flameless oxidation in the formation, and withdrawing hydrocarbon fluid through the output well.

7. In a method of recovering hydrocarbons from a hydrocarbon oil-bearing formation which is penetrated by an input well and an output well, the steps comprising transmitting a combustible fluid including free oxygen into the input well, contacting the combustible fluid with a suitable catalyst in the portion of the input well that penetrates the oil-bearing formation to initiate oxida-

tion in the formation, subsequently discontinuing the transmission of combustible fluid through the input well but transmitting sufficient quantities of free oxygen-containing gas therethrough to sustain flameless oxidation in the formation, and withdrawing hydrocarbon fluid through the output well.

8. In a method of recovering hydrocarbons from a hydrocarbon oil-bearing formation which is penetrated by an input well and an output well, the steps comprising transmitting a combustible fluid including free oxygen into the input well, contacting the combustible fluid with a suitable catalyst of the iron group in the portion of the input well that penetrates the oil-bearing formation to initiate oxidation in the formation, subsequently discontinuing the transmission of combustible fluid through the input well but transmitting sufficient quantities of free oxygen-containing gas therethrough to sustain flameless oxidation in the formation, and withdrawing hydrocarbon fluid through the output well.

9. In a method of recovering hydrocarbons from a hydrocarbon bearing formation which is penetrated by an input well and an output well, the steps comprising transmitting free oxygen-containing gas into the formation through the input well, initiating and maintaining flameless oxidation of carbonaceous material in the formation to heat the oil therein to a temperature within the range of 200° to 600° F. and effect distillation of relatively low boiling point components of the oil, and withdrawing distilled components of the oil through the output well.

10. In a method of recovering hydrocarbons from a hydrocarbon bearing formation which is penetrated by an input well and an output well, the steps comprising transmitting free oxygen-containing gas into the formation through the input well, initiating and maintaining flameless oxidation of carbonaceous material in the formation to heat the oil therein to a temperature within the range of 200° to 600° F. and effect cracking of relatively high molecular weight hydrocarbons, and withdrawing cracked components of the oil through the output well.

FREDERICK E. FREY.