The present invention relates to the production of oil, and more particularly to an improved method in which heat is generated in the production horizon and is directly applied to the oil-containing reservoir to provide a thermal drive for recovery of the oil.

Petroleum is generally found in sandstones or porous limestone situated between impervious layers of shale or the like. Initially, the oil is usually found to be associated with lighter hydrocarbons such as methane and ethane, which may exist as free gases in contact with the oil or dissolved in the oil. When such oil bearing sands are reached by drilling, the expansive force of the gas, either free or dissolved under the pressure existing at the depth of the oil reservoir, moves oil and gas toward the region of low pressure around the well bottom. With conditions at the casinghead uncontrolled, the rapid flow of oil and gas from the well creates a gusher and flush production results. After the initial pressure existing has diminished with the escape of most of the gas associated with the oil from the well, the motive power bringing oil to the surface is largely dissipated. At this stage, the well is put to pumping with resultant increased production of oil from the well together with additional amounts of gas. In time the flow of oil produced by pumping diminishes to the point where pumping is no longer economical. The remaining oil has little pressure exerted upon it by the small amount of residual gases or vapors remaining in the reservoir and the heavier hydrocarbons present assume a more viscous, semi-solid state which tends to choke the pores of the sand preventing drainage of the oil to the well bottom.

In an attempt to increase productivity of such wells, the method of repressuring has been adopted. This operation involves forcing back into selected central wells either natural gas taken from other wells or air. The gas injected into the selected well under pressure passes through the porous oil-containing sands and is vented from adjacent wells. By this procedure, the gas mechanically forces some of the heavier oil into the well bottoms, and entrains any hydrocarbons existing in vapor form in the reservoir.

Upon continued operation, this method also becomes unprofitable and it must be abandoned even though the reservoir is only partially depleted with respect to the oil initially present.

Further attempt to increase production from such wells involves final resort to the so-called flooding procedure. In this procedure water under pressure is injected into selected wells and the entire oil reservoir is scoured with water bringing to the surface from adjacent venting wells a further portion of the residual oil. After practicing this method the oil field can no longer be utilized for further production.

It is well-known that oil fields which have been subjected to the foregoing successive treatments still contain in the sands about half of the oil known to be initially present.

It has been recognized heretofore, that the application of heat to the oil-containing sands tends to increase production of oil from oil reservoirs. For example, it has been proposed to inject heated gaseous products of combustion into partially depleted oil reservoirs in an attempt to drive out the residual oil by reducing the viscosity and thereby facilitating flow. In some instances, combustion of the oil itself has been proposed as the source of heat.

It has also been proposed to utilize steam under pressure by passing the same through the oil-containing sands. Such procedures have serious and inherent disadvantages which are common to all, and, in addition, further disadvantages are to be found which are specific to each method.

One of the main disadvantages common to above procedures is the loss of heat amounting to a major portion of the total heat input. Upon injection of heated gaseous products of combustion or steam into an open well, heat will spread in all directions from the bottom of the well by conduction. Since the heat conductivity of the oil-containing sands and the adjacent impervious shale strata are of approximately the same order of magnitude, regions of equal temperature (isotherms) will approximate concentric spheres with the bottom of the well at the center of the sphere. In other words, heat will travel outwardly, horizontally and vertically, the mass of rock being heated varying with the cube of the radius from the well center. In addition, much of the sensible heat contained in the gaseous products of combustion will be vented through the open well. In an attempt to reduce these serious heat losses, the input well has been closed and pressure developed to drive the hot products of combustion into the porous oil-containing sands to increase the travel of heat horizontally toward the venting or producing wells communicating with the oil sands. Thus, the enlarging surfaces of equal temperature (isotherms) tend to take the form of an oblate spheroid. However, with increasing passage
horizontally of the heat, a greater portion is di-
sipated and losses by conduction vertically away
from the oil-containing sands increases. Thus,
with a steady heat input a very appreciable por-
tion of the total heat is lost by conduction ver-
tically into and through the layers of shale, al-
though the movement of the heat in a horizontal
direction through the oil-containing sands is some-
what more extensive.

It is a further object of the invention to pro-
vide an improved method of thermal drive for
the recovery of oil from oil reservoirs whereby
minimum portions of the hitherto unrecoverable
oil may be produced. It is a further object of the
invention to provide an improved method of thermal drive for
the recovery of oil in which there is a minimum of
heat losses.

Still another object of the invention is to pro-
vide a thermal drive method for the production of
gas which both sensible heat and latent heat
of the heating mediums are fully utilized and
perform interdependent functions.

A further object of the invention is to pro-
vide an improved method of recovery of oil in
which there is a minimum loss of oil due to un-
controlled oxidation and combustion thereof.

A still further object of the present invention is to provide a novel type of gas burner adapted to
operate at pressures in excess of existing well
pressures.

These and other objects and advantages of the
present invention will become apparent from the
following detailed description.

The method of the present invention generally
comprises introducing a combustible gas and a
combustion supporting gas into a selected por-
tion of an oil reservoir, producing combustion of
said combustible gas therein, introducing an un-
heated fluid into the selected portion of the oil
reservoir, and recovering the oil from another
selected portion of the reservoir.

The method of the invention is preferably
practised by utilizing an existing oil well com-
manting with the oil well as the input well,
and employing one or more existing adja-
cent wells as the venting wells. If necessary,
however, new venting wells may be drilled closer
to the selected input wells. The bottom of the
input well constitutes a combustion chamber into
which a combustible gas and a combustion sup-
porting gas such as air are introduced under
pressure. The combustion supporting gas may
be air, oxygen, or mixtures thereof, or any
permanent gas containing sufficient oxygen to
effect complete combustion. The combustible gas
may be any heating gas such as producer gas,
water gas or natural gas. The input well is
capped or closed in at the casinghead so that any
desired pressures may be developed. Upon
ignition and continued combustion of the gas,
heat generated products of combustion are de-
veloped, which under the existing pressure are
forced into the oil reservoir. The heat imparted
in this manner to the oil in the sands volatilizes
a portion of the oil and reduces the viscosity of
the remaining heavier constituents of the oil tend-
ing to fluidize the same. The vaporized portions
of the oil are entrained by the stream of gaseous
products of combustion and move therewith to-
ward the venting well, while the fluidized heavier
portions of the oil are mechanically forced un-
der pressure of the gaseous products of com-
bustion toward the venting well. As the vapor-
ized portions of the oil move into cooler regions
of the oil-containing sands, they are partially
condensed and release the latent heat of con-
densation at that point, which together with
the sensible heat in the gaseous products of com-
bustion serves to increase the temperature in
regions of the sands more remote from the in-
pit well. Thus, the entire oil reservoir is
progressively heated and the oil in vaporous
and/or fluid state is forced into the venting well
bottom where it is removed by ordinary pump-
ing means. Vaporization of a portion of the oil,
and, in addition, formation of steam from the
connate water adds to the total volume of gases,
facilitating removal of the oil from the reservoir.

With increasing temperature in the oil reser-
voir, the additional air in excess of that sup-
plied to the burner causes partial oxidation of
some of the heavier components of the oil.
This oxidation forms pitch-like bodies in the oil.
These burn at the higher temperatures developed
later producing additional heat liberated in situ
in the oil, which further aids in driving the oil from
the sands toward the venting well.

One of the principal features of the present
invention is the reduction of heat losses due to
conduction of heat vertically from the well bot-
tom where combustion occurs. This reduction of
heat losses is accomplished through reversal of
the flow of heat away from the combustion
chamber in a vertical direction by reversing
temporarily the temperature gradient existing
from the combustion chamber through the adja-
cent portion thereof. The invention further pro-
vides for redirecting in a horizontal direction
through the oil-containing sands of the oil
reservoir, the heat regained by reversal of the
flow. This elimination of heat losses according to
the method of the present invention may be
affected in any one of several ways and either
by means of a cyclic process or a continuous
process.

According to one embodiment of the invention,
combustion at the bottom of the input well is
maintained as the input well is moved away from
the combustion chamber and the input well bottom by conduction in a
vertical direction through the shale strata adja-
cent to the oil-containing sands of the reser-
voir. At the end of this period flow of the com-
bustible gas is shut off and combustion ceases.
However, the introduction of air under pressure
is maintained. Thus, cold air entering the
bottom of the hot wet abstracts heat from the
walls of the well thereby becoming heated.
The heated air under the existing pressure is forced
horizontally through the oil sands. A continued
supply of cool air into the well bottom progres-
sively lowers the temperature of the well to a
point where the well becomes cooler than the
surrounding rock or shale. At this point the
temperature gradient previously existing from
the well toward the shale strata is reversed and
a flow of heat is initiated from the shale strata
back toward the well. The heat thus regained
into the well bottom serves to further heat the
air which passes horizontally into the oil-}
containing sands. Thus, an appreciable portion
of the heat lost by vertical conduction is regained.
Under continuous heat input, such heat would
be permanently lost. After a suitable interval of recuperating some of this lost heat, combustion is again initiated, and the cycle is repeated. The time in which a complete cycle occurs may be widely varied dependent on varied 2,584,606 5 be permanently lost. After a suitable interval of recuperating some of this lost heat, combustion is again initiated, and the cycle is repeated. The time in which a complete cycle occurs may be widely varied dependent on varied 2,584,606 5 be permanently lost. After a suitable interval of recuperating some of this lost heat, combustion is again initiated, and the cycle is repeated. The time in which a complete cycle occurs may be widely varied dependent on varied 2,584,606 5 be permanently lost. After a suitable interval of recuperating some of this lost heat, combustion is again initiated, and the cycle is repeated. The time in which a complete cycle occurs may be widely varied dependent on varied 2,584,606 5 be permanently lost. After a suitable interval of recuperating some of this lost heat, combustion is again initiated, and the cycle is repeated. The time in which a complete cycle occurs may be widely varied dependent on varied 2,584,606 5 be permanently lost. After a suitable interval of recuperating some of this lost heat, combustion is again initiated, and the cycle is repeated. The time in which a complete cycle occurs may be widely varied dependent on varied 2,584,606 5 be permanently lost. After a suitable interval of recuperating some of this lost heat, combustion is again initiated, and the cycle is repeated. The time in which a complete cycle occurs may be widely varied dependent on varied 2,584,606 5 be permanently lost. After a suitable interval of recuperating some of this lost heat, combustion is again initiated, and the cycle is repeated. The time in which a complete cycle occurs may be widely varied dependent on varied 2,584,606 5 be permanently lost. After a suitable interval of recuperating some of this lost heat, combustion is again initiated, and the cycle is repeated. The time in which a complete cycle occurs may be widely varied dependent on varied 2,584,606 5 be permanently lost. After a suitable interval of recuperating some of this lost heat, combustion is again initiated, and the cycle is repeated. The time in which a complete cycle occurs may be widely varied dependent on varied 2,584,606 5 be permanently lost. After a suitable interval of recuperating some of this lost heat, combustion is again initiated, and the cycle is repeated. The time in which a complete cycle occurs may be widely varied dependent on varied 2,584,606 5 be permanently lost. After a suitable interval of recuperating some of this lost heat, combustion is again initiated, and the cycle is repeated. The time in which a complete cycle occurs may be widely varied dependent on varied 2,584,606 5 be permanently lost. After a suitable interval of recuperating some of this lost heat, combustion is again initiated, and the cycle is repeated. The time in which a complete cycle occurs may be widely varied dependent on varied 2,584,606 5 be permanently lost. After a suitable interval of recuperating some of this lost heat, combustion is again initiated, and the cycle is repeated. The time in which a complete cycle occurs may be widely varied dependent on varied 2,584,606 5 be permanently lost. After a suitable interval of recuperating some of this lost heat, combustion is again initiated, and the cycle is repeated. The time in which a complete cycle occurs may be widely varied dependent on varied 2,584,606 5 be permanently lost. After a suitable interval of recuperating some of this lost heat, combustion is again initiated, and the cycle is repeated. The time in which a complete cycle occurs may be widely varied dependent on varied 2,584,606 5 be permanently lost. After a suitable interval of recuperating some of this lost heat, combustion is again initiated, and the cycle is repeated. The time in which a complete cycle occurs may be widely varye
from the well bottom due to conduction and passage of the gaseous products of combustion into the oil sands. It will be seen that the isotherms are approximately of the form shown and that appreciable amounts of heat developed in the well bottom are dissipated by heating the adjacent strata of rock or shale.

After combustion has ensued for a time sufficient to insure heating of the oil sands by passage of the gaseous products of combustion through, valves 8 and 10 in lines 4 and 5 are closed while valve 11 in the excess air line 7 remains open. This effectively shuts down operation of the burner in the input well bottom and permits continued flow of cool air under pressure through line 7 to the input well bottom. The continuous supply of air progressively cools the well bottom until the temperature gradient existing between the well bottom and the adjacent strata of rock or shale is reversed so that heat dissipated by conduction into the rock flows back into the well heating the incoming air. The air thus heated continues in its path of movement under pressure in a horizontal direction into the oil-containing sands of the reservoir.

The products of combustion together with excess air progressively penetrate through the sand and reach the venting well. The oil sands, of course, are hottest at the input end, but are gradually, continually and progressively heated until the heat reaches the products of combustion and excess air. The portion of oil thermally driven into the venting well which are in the vapor state are removed to a suitable stripping plant for extraction from the gaseous products of combustion and the excess air. A pump 12 is provided for the venting well 2 to remove liquid hydrocarbons of the oil driven out of the sands into the well bottom. In the cyclic procedure of the invention embodying the use of steam, after a suitable period of time during which the burner is in operation, valves 8 and 11 are closed, completely shutting off the flow of air and gas to the input well bottom. Thus, the flame issuing from the gas burner 3 is extinguished. A slow stream of water is then introduced into the well bottom from line 8 through piping 13. Upon contact with the highly heated well bottom, the water flashes into steam and is forced into the oil-containing sands of the reservoir. The steam continues its passage through the oil-containing sands until it reaches a region below the condensation temperature at the existing pressure in the reservoir. At this location the steam condenses releasing all of its latent heat of vaporization thereby warming the oil in the formation in that vicinity. By continued condensation of steam, the latent heat of condensation released sufficiently warms the oil-containing sands at the strata where condensation has taken place so that continued condensation of the steam does not occur at the same location. The warming which occurs allows the steam to move farther into the sands toward the venting well before condensation again occurs. Thus, the sands are progressively heated until the steam reaches the venting well.

The continuous vaporization of the water into steam by flashing during this phase of the method, rapidly cools the walls of the input well and ultimately they become cooler than the adjacent strata of rock or sand which were heated by conduction during the burner operation phase of the method. At this point the temperature gradient reverses and heat flows from the heated shale or rock into the well bottom generating additional steam which continues to pass in a horizontal direction into the oil sands. Thus, the heat dissipated into the strata of shale or rock is regained and redirected into the oil sands in the form of latent heat contained in the steam. The cycle is then repeated until the well is no longer productive of oil.

In the alternative procedure embodying continuous operation, valves 8 and 10 are initially open whereby the mixture of combustible gas and air flows through lines 4 and 5 into the gas burner 3 at the input well bottom. Valve 7 is open to supply excess air under pressure through line 7 and the burner is ignited. Valve 14 in waterline 9 is then opened permitting flow of a slow continuous stream of water through piping 13 into the input well bottom. Thus, the sensible heat contained in products of combustion from the continuously operated burner 3 is in part utilized in supplying the latent heat of vaporization which effects continuous vaporization of the water introduced into the input well bottom. The resulting mixture of heated gaseous products of combustion and steam are forced by the pressure developed in the input well bottom through the oil-containing sands where they heat and vaporize and fluidize the residual oil. The oil is driven mechanically by entrainment in the gases into the venting well and is removed therefrom through line 15 with the aid of pump 12. Line 16 conducts gas and vapor to a processing plant.

The sensible heat of the gaseous products of combustion and steam produced by burner 3 is not dissipated by vertical conduction into the surrounding strata of rock and shale, but is primarily utilized to vaporize the water continuously supplied to the well, which in the form of steam is then horizontally forced through the oil-containing sands. Thus, most of the total heat input into the system is utilized for the desired purpose of heating the oil-containing sands.

In this method of operation the well bottom and adjacent portions of rock serve as the equivalent of an oven where the temperature of the well bottom itself may be at a high temperature the continuous supply of water prevents the rock and well bottom from attaining temperatures much in excess of the temperature of water boiling under the prevailing pressure. The relatively low temperatures do not favor loss of heat in a vertical direction. Such losses would be favored if the rock were heated to a much higher temperature, as would be the case if products of combustion alone carried the heat.

Use of liquid water in conjunction with a burner favors the horizontal movement of heat and minimizes the undesirable losses in a vertical direction.

Referring now to Figure 2, the construction and operation of the novel gas burner 3 is described in detail. In this figure, the gas burner 3 is inserted into the well bottom so that it is positioned centrally within the shot hole 21 at the well bottom. The burner 3 positioned in the shot hole 21 is attached to tubing consisting of a central pipe 22 for supplying gas located within an outer pipe 23 inserted through the casinghead of the well for supplying air. The outer annular duct formed by pipes 22 and 23 and the cylindrical duct within pipe 22 are
connected through an orifice controlled by a stem valve 24 positioned in tapered end 25 of pipe 22 and an annular duct 26 formed by baffles 27 positioned within the pipe 22. An elongated stem 28 is connected to valve 24 and extends through pipe 22 at the top of the tubing where a wheel or handle 29 is attached. This provides a means of finely adjusting the ratio of air and gas fed to burner 3.

A mixing chamber 33 is connected to baffle 27 and contains a cylindrical body having multiple constrictions 31 therein. A lower extension 32 of pipe 23 carries a metal cage 33 comprising a metal base portion 34 and spaced vertical rods 35 extending upwardly therefrom. The rods 35 are attached at their upper ends to a threaded metal ring 36. A hollow cylinder of porous ceramic material 37 is inserted into the lower annular extension 32 of pipe 23, which is threaded on its external periphery. Thus cylinder 37 is fixed in position on extension 32 by means of the threaded metal ring 36 and base 34. The ceramic cylinder 37 may be made of suitable heat insulating or refractory material such as brick, or the like, used for furnace linings. The porous cylinder 37 contains a cavity 38 tapering toward the inlet end which communicates with the chamber 39. This cavity 38 which constitutes the combustion chamber of burner 3 is filled with granular refractory material. Cylinder 37 is provided with a number of horizontal ports 39 which are so located that they lie in different vertical planes than the rods 35 of the cage 33. (This structure is more clearly shown in Fig. 3.)

A combustible gas under regulated pressure is fed into pipe 22 through line 5 in which is inserted appropriate regulators and flow meters. Air under regulated pressure is supplied to the pipe 23 surrounding the pipe 22 through line 4 passing through an appropriate regulator, flow meter and valve 8. Thus, the ratio of air to gas may be maintained constant or may be varied. For example, the ratio of gas to air may be one cubic foot of gas to ten cubic feet of air. A mixture is introduced into pipes 22 and 23 mix in the mixing chamber 30 upon passage through duct 25 and valve 24, respectively. A main air supply is introduced into casing 29 through line 1 controlled by valve 11. The pressure of the main air supply is maintained at a value lower than the pressure of the air and gas fed to the burner. The combustible mixture of gas and air issuing from the ports 39 in the ceramic cylinder 37 of the burner 3 may be ignited by any suitable means such as described above. When thus ignited, the flame pops back into the cavity 38 of the ceramic cylinder 37. A static zone of burning is established within the cavity 38 when the velocity of the explosive backflash equals the forward flow of the gas and air mixtures through chamber 39 into cavity 38. At this point, the main air and gas mixture is ignited.

As long as the pressure existing outside of the porous cylinder 37 of the burner is not permitted to exceed the pressure of the forward flow of combustible gas and air fed to the burner, the burner will operate continuously. The temperature at the end of the combustible products and the excess air from the main air supply will depend upon the ratio of combustible gas and air fed to burner 3, and also on the ratio of air supplied through the main air supply. The refractory material inside of the burner 3 may reach a temperature of 3500° F., where it is in direct contact with the flame. However, the metal parts of the cage 33 of the burner will not be subject to excessive temperatures.

Figure 3 clearly advantageously illustrates the construction of a burner 3 relative to the ports 39 in porous cylinder 37 and metal cage rods 35. From this figure it is clearly seen that the vertical rods 35 are disposed in vertical planes which are not common to the vertical planes occupied by ports 39 in cylinder 37. In this construction, direct impingement of the flame or hot gases of combustion upon rods 35 is avoided.

The burner also operates efficiently under the conditions, present in the alternative procedures of the invention involving supplying a continuous supply of water to the well bottom. As long as the pressure of the water outside of the porous ceramic cylinder 37 of the burner 3 does not exceed the pressure of the forward flow of gas and air fed to the burner, the burner will continuously operate.

The method of the present invention is more efficient than those heretofore practiced, since heat losses are largely reduced.

Furthermore, the preferred embodiments of the invention involving the use of water supplied to the input well, combined with operation of the gas burner, either in a cyclic manner or continuous manner, presents many advantages over the use of either steam alone or products of combustion alone. Not only are heat losses eliminated or reduced to a minimum by the flash vaporization of the water introduced into the input well, but the latent heat of condensation of the steam is realized in heating the oil in the oil-containing sands while avoiding the disadvantages encountered when using steam alone.

The process described produces the more volatile and more valuable parts of the oil, and burns the non-volatile valueless parts, thus furnishing part of the necessary heat.

Having thus described our invention, we claim:

1. A cyclic method for the recovery of oil from an oil-bearing geological formation which comprises alternately the steps (a) and (b), said step (a) comprising introducing into said formation through an input well, at a pressure greater than that exerted therein, a combustible gaseous mixture, effecting combustion of said mixture in said formation to produce hot products which penetrate said formation and impart heat to and reduce the viscosity of the oil present therein, said combustion products and said oil being moved through said formation toward a venting well; said step (b) comprising introducing a stream of fluid heat transfer medium through said input well into that portion of said formation where combustion was effected in step (a) to heat said heat transfer medium, causing the so-heated transfer medium to penetrate said formation to impart heat to and reduce the viscosity of the oil present therein, said heat transfer medium and said heated oil being moved through said formation toward a venting well, said steps (a) and (b) being alternated at appropriate intervals.

2. The process of claim 1 wherein the fluid heat transfer medium is air.

3. The process of claim 1, wherein the fluid heat transfer medium is water which is converted to steam upon introduction into the formation through the input well, and in which step (b) is discontinued and step (a) is repeated.
when the heat requisite to effect such conversion of water into steam has been dissipated.

4. A method for the recovery of oil from an oil bearing geological formation having an input well and a venting well, which comprises introducing through said input well, into said formation, a combustible, gaseous, mixture, at a pressure in excess of that existing in said formation, and water, effecting combustion of said mixture in said well to produce combustion products and steam, under a pressure sufficient to cause said combustion products and steam to penetrate into said formation toward a venting well to impart heat to and reduce the viscosity of the oil present in the formation, and recovering oil from a venting well.

5. The process of claim 4 wherein the combustible, gaseous, mixture employed is producer gas.

6. The process of claim 4 wherein the combustible, gaseous, mixture employed is water gas.

7. The process of claim 4 wherein the combustible, gaseous, mixture employed is natural gas.

8. A method for the recovery of oil from an oil bearing geological formation having an input well and a venting well, which comprises continuously introducing through said input well, into said formation, a combustible, gaseous, mixture, at a pressure in excess of that existing in said formation, and water, effecting combustion of said mixture in said well to produce combustion products and steam, under a pressure sufficient to cause said combustion products and steam to penetrate into said formation toward a venting well to impart heat to and reduce the viscosity of the oil present in the formation, and recovering oil from a venting well.

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