

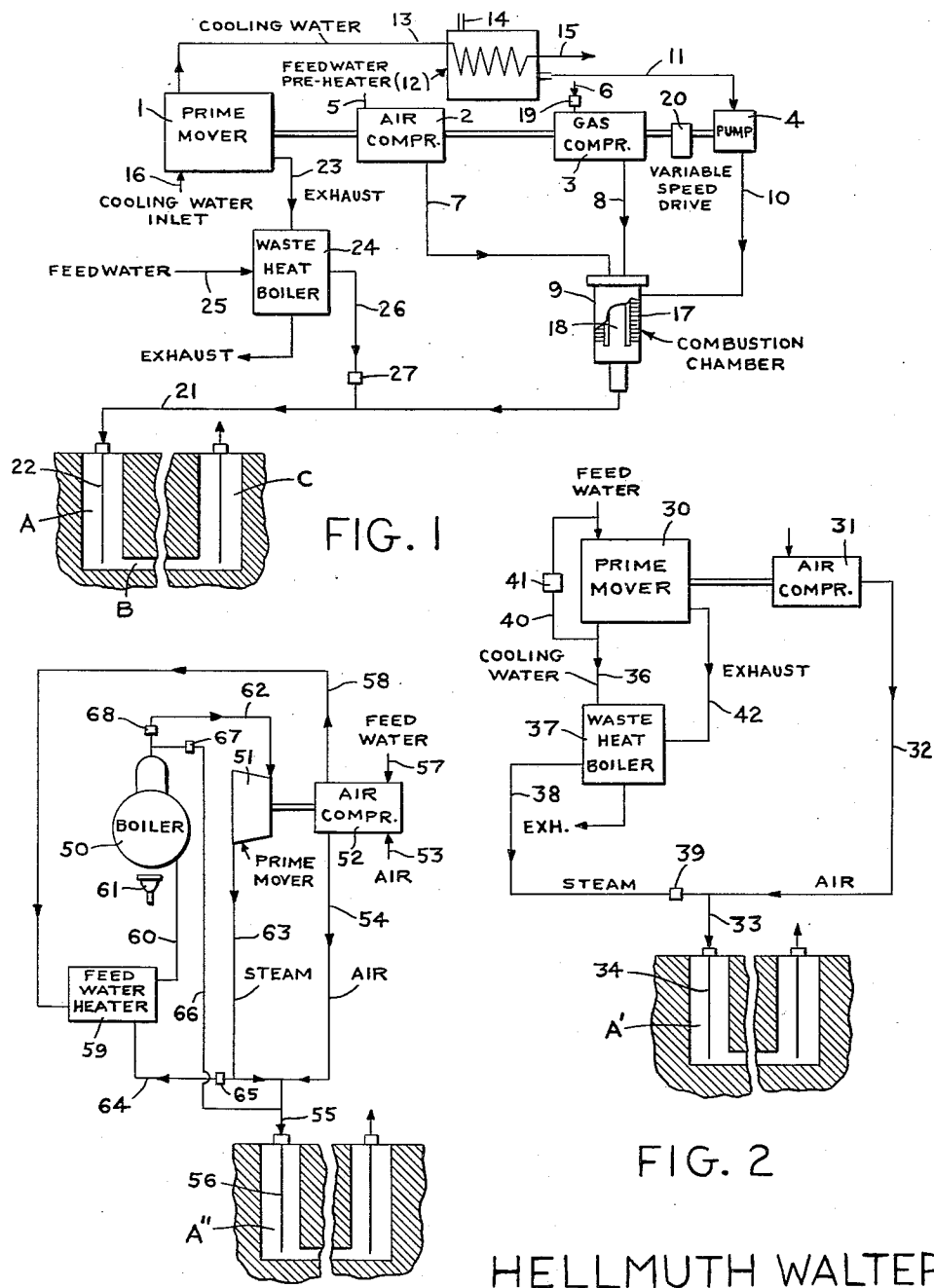
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METHOD FOR OIL RECOVERY WITH "IN SITU" COMBUSTION

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METHOD FOR OIL RECOVERY WITH "IN SITU" COMBUSTION

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This invention relates generally to the problem of oil recovery and more particularly to a method and apparatus for reducing the retentive forces holding the especially low gravity oil in an oil bearing formation and for increasing the flow of such residual oil after the retentive forces are thus reduced so that a greater recovery of oil can be effected from wells which have partially or wholly ceased producing or have never been productive at all.

Even with the most efficient methods and apparatus for producing well operation and control, wherein the natural formational energy, pneumatic or hydrodynamic flow methods, with various mechanical devices are primarily utilized, only a fraction of the oil originally present in the oil bearing formation is recovered. Hence, in an effort to recover the residual oil which remains after these primary efforts, secondary methods of oil recovery have been developed.

These secondary methods of oil recovery follow the theory that the expulsive forces and the retentive forces acting on the oil in the oil bearing formation have reached an equilibrium and accordingly, in order to secure further recovery of oil from the oil bearing formation it is necessary to unbalance the equilibrium by either adding artificial energy to restore or replace the expulsive forces necessary to move the oil into the producing well or to reduce the forces which resist the movement of the residual oil through the oil bearing formation or to provide a combination of both in connection with such recovery.

Certain accepted secondary methods of oil recovery have been utilized for many years, such for example as gas injection or repressurizing, gas and air drive, or water flooding, all of which act to substitute artificial energy to restore or replace the expulsive forces necessary to move residual oil from the oil bearing formation.

However, various modifications of these basic methods of secondary oil recovery have been developed in an effort to aid recovery by providing in addition, means to reduce the viscosity of the oil, and the interfacial tension between the residual oil and the immense surface area of the oil bearing sands or rock strata to which the oil is adhered.

It has been found in particular that the heating of the oil bearing formation itself produces highly advantageous results in that the viscosity of the residual oil decreases with increasing temperature and as a result the retentive forces are considerably reduced. It is then easier to move the oil through the oil bearing formation to a producing well.

There are basically two methods of heating the oil bearing formation:

(a) Injecting some heat carrying medium such as hot gas or steam into the oil bearing formation which heat carrying medium may be produced at the surface and delivered to the inlet well or in the inlet well itself, and

(b) Injecting air or other free oxygen carrying gas into the formation and producing combustion with the oil

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present in the formation. This second method is more popularly referred to as "in situ" combustion.

Injection of steam alone, as the heat carrying medium, fails because as the steam delivers its latent heat to the oil bearing formation it condenses and after condensation there is not enough water volume available to drive the residual oil to the producing well. While it is feasible to use sufficient steam to provide steam at the producing well itself, such process would be too costly for practical application. Similarly, injection of gas alone as the heat carrying medium has its shortcomings. First, the specific heat of gas is low and hence the amount of gas required is very high. Second, the gas tends to drive the water present in the oil bearing formation before it drives the oil out. It is well known that the presence of some water in the formation increases the relative permeability for oil. Therefore, if the formation is depleted from its water content, it becomes more difficult to drive the oil to the production wells.

Heating the oil bearing formation by combustion "in situ" also has its shortcomings and disadvantages. The ignition of the oil and thus the starting of combustion is always a problem. In addition, the symmetrical propagation of the combustion zone and sustaining of the combustion in the ground is another problem. Further, once the combustion zone is established it may not propagate in all directions radially from the injection well but in sectors only although the injected air will be moving in all directions and, last, even when combustion is effected "in situ" by reason of this tendency to advance in sectors it was further found that heating was not uniform and that combustion did not take place in all layers of the sector of the oil bearing sands effected. As a result, there is in this process of "in situ" combustion, heavy losses of the injected air since a considerable part of air dissipates into the field or is produced from the producing well without being utilized for combustion. To improve the propagation of the combustion front gas mixtures with a low amount of oxygen (6% and under) have been injected. This, however, requires large amounts of gas to be compressed and injected in order to generate same amount of heat "in situ" and makes the economical results of process questionable.

The use of gas and superheated steam as the heat carrying medium was found feasible to accomplish the combined heating and driving required for recovery of residual oil, but in order to make the process economical where this mixture was utilized it was necessary to recover all the heat originating from the consumed fuel and to apply it for a useful purpose. This meant that the heat in the cooling water and exhaust of the prime mover and the compressors had to be recovered as was illustrated and shown in my copending application Serial No. 531,567, filed August 30, 1955.

The present invention seeks to combine the advantages of the use of gas and superheated steam with combustion "in situ" to overcome all the above indicated problems presented by the independent application of these methods of oil recovery.

According to the present invention, a heat carrying and driving medium is generated at the surface above the oil bearing formation. This heat carrying and driving medium will comprise alternate types of mixtures depending on the apparatus utilized to obtain the mixture. One mixture, for example, will consist of superheated steam, inert gases such as nitrogen and carbon dioxide, etc., and free oxygen. In such mixture, the amount of free oxygen will be not less than 6% by weight of the mixture and preferably between 9 and 15 percent by weight of the mixture. The amount of steam would vary between 30 and 70 percent and the balance in each case being inert gas or gases.

Another medium would consist of a mixture of superheated steam and compressed air where the steam would be between 30 to 70 percent and compressed air between 70 and 30 percent by weight of the mixture.

In each instance the mixture will vary depending on the stage of oil recovery operation.

According to the present invention, the heat carrying and driving medium will be delivered and injected into the inlet well or wells for the oil bearing formation at a pressure limited only by the separation pressure of the overburden above the oil bearing formation as is well known in the art, and will be at temperatures generally not lower than 400° F. The temperature can, of course, be varied up to 800° F. but for all practical purposes a temperature of approximately 600° F. has been found sufficient to start and accomplish the desired "in situ" combustion.

The heat carrying and driving medium is injected into the input well or wells continuously, the medium being varied as to mixture and temperature depending on the desired conditions of operation. For example, where initially it is desired to heat the formation a higher temperature and less oxygen will be utilized until the residual oil starts moving away from the input well and the oil bearing formation area surrounding the input well has been raised to a temperature above 350° F. In effect, the injected mixture heats the oil bearing formation moving from the input well into the formation continuously until the formation has cooled the mixture to a point where the steam starts to condense some distance from the input well. This condensation simultaneously adds additional heat to the formation from the latent heat of the steam and acts to maintain the water content of the desired level for oil recovery.

In this respect the heating of the oil bearing formation surrounding the well is similar to that described in co-pending application Serial No. 271,512, filed February 14, 1952, the effect of this heating process being to reduce the viscosity of the oil in the oil bearing formation so that it may be driven, by the heat carrying and driving medium being continuously injected, towards the producing well or wells selected for the particular oil bearing formation in which the process is being utilized. The heating of the oil bearing formation between the inlet well and the producing well will of course occur progressively as the condensation zone advances in the oil bearing formation.

After the mixture has thus acted to move the crude oil towards the producing well we find in that portion of the formation now clear that there still remains remnants of hydrocarbon matter, which matter will react with the oxygen present in the mixture to produce the exothermic reaction which is identified as "in situ" combustion. The amount of oxygen at this point can of course be varied and increased to the desired maximum concentration of 15 percent. The heat developed from this exothermic reaction or "in situ" combustion will be picked up by the continuously supplied injection mixture and used to increase the rapidity with which the remaining portions of the oil bearing formation will be heated and hence decrease the period of time required for recovery of the oil in the oil bearing formation. In addition, and more important, from a practical and commercial viewpoint, this will reduce the amount of fuel that would ordinarily have been combusted or supplied from outside the formation in order to obtain the necessary heat for recovery of the residual oil if the gas and superheated steam mixture or other methods of oil recovery similar thereto had been utilized alone.

With the process progressing we will have basically three zones around each injection well. In the first zone around the well the formation has been heated to or above the ignition temperature. A gas mixture containing free oxygen is continuously driven through this zone,

but no reaction can take place here, since all of the oil either has been driven outside of this zone or has been combusted in this zone.

The formation in the second zone has been heated to or above the ignition temperature too. Injected gas mixture containing some free oxygen passes this zone and since some hydrocarbon matter is still present, reaction takes place and hydrocarbon matter is combusted.

In the third zone the temperature of the formation decreases gradually from the ignition temperature to the original formation temperature. No reaction can take place in this zone, since though enough hydrocarbon matter is available, the ignition temperature has not been reached yet. Even if the gases driven through this zone do contain some free oxygen (which did not react in the second zone) it will pass without reacting and act as a heating medium only.

The present process is thus in no way hampered by ignition trouble since reaction with the remnants of hydrocarbon matter which remain as the oil is moved from the oil bearing formation to the production well will start spontaneously as soon as the reaction temperature is reached in any portion of the formation, assuming of course that the oxygen is present. Furthermore, there is no danger that the reaction or combustion would advance in only one direction since the reaction starts everywhere in the oil bearing formation around the inlet well as soon as the reaction temperature is reached and so long as hydrocarbon matter is present. Similarly, there is no problem that the reaction will stop in some part of the formation because even these parts of the formation where the reaction has stopped for some reason temporarily will be heated gradually by the injected hot gases to the ignition temperature and thus the reaction will be started again simultaneously.

This process has been tested practically in an oil field pilot project in the Parker Pool, Clark County, Illinois. The injected mixture contained on the average over the whole duration of the test

	Percent by weight
Steam	38
Nitrogen	49
Carbon dioxide	6
Oxygen	7

At times the oxygen content was raised to above 15%. Average injection pressure was 350 p. s. i. g. Average injected mixture temperature between 400° F. and 900° F. The average Orsat analysis of the dry gas, produced by the production wells was

Oxygen	0 to 2 percent by vol.
Carbon dioxide	13 to 15.5 percent.
Carbon monoxide	traces only.
Nitrogen	balance to 100 percent.

This proved that combustion "in situ" did take place. Toward the latter part of the process the oxygen content of the producing wells increased somewhat (to 3.0 percent) and the CO₂ decreased (to 12 percent). This can be explained by channeling of the formation and some of the mixture passing through the channels to the production wells without encountering any more combustible matter under way.

Of the total heat used to heat up the producing formation, 60 percent was developed outside the formation and carried to the formation by the injected mixture and 40 percent was developed by combustion "in situ."

For a superheated steam and compressed air medium steam in ratios between 30 to 70 percent and compressed air in ratios between 70 and 30 percent would be combined above the ground and injected into the ground depending on the stage of operation. Thus, initially greater percentages of steam will be utilized to obtain the desired heating while at subsequent stages of the operation the mixture will be varied to obtain optimum "in situ" combustion and thereby secure the greatest heat recovery

from such combustion. The preferred composition of the mixture following initial operation would be approximately 50 percent by weight steam and 50 percent by weight air, the analysis being as follows:

	Percent by weight
Steam -----	50
Nitrogen -----	38.5
Oxygen -----	11.5

This process is advantageous since all the oxygen compressed with the air is combusted "in situ" and the amount of fuel to be combusted outside the formation is further reduced.

It is understood that applying any of the described processes that the composition of the mixture does not have to be kept the same at all times. It might be advisable to inject more steam during the first heating period and more gas during the later period when the formation is heated to some extent already and recovery of oil is being effected. However, this is empirically determined by the particular conditions of the variables in the particular oil bearing formation on which the process is being utilized.

The present invention is further directed to apparatus which is adapted to supply the desired heat carrying and driving medium wherein substantially all of the waste heat of the fuel utilized is recovered so that the highest percentage of energy from the fuel is consumed and converted into usable form in the heat carrying and driving medium supplied to the inlet well in connection with the above described methods of oil recovery.

Accordingly, it is an object of the present invention to provide apparatus adapted to provide a heat carrying and driving mixture having either superheated steam or combustion gases or both and oxygen between 6 to 15 percent of the mixture by weight.

In accomplishing the above methods and objects of the present invention preferred forms of the apparatus consisting of various features and construction of parts are described in connection with the accompanying drawings in which:

Figure 1 illustrates a fragment of an injection well for an oil bearing formation with the system and arrangement of the general apparatus for the practice of the present invention shown diagrammatically.

Figure 2 is a diagrammatic sketch of another system and arrangement of apparatus for the practice of the present invention.

Figure 3 is a still further modification in diagrammatic form of the system and apparatus for the practice of the present invention.

Apparatus adapted to supply steam combustion gases and free oxygen

Referring to the drawings, Figure 1 shows diagrammatically a prime mover 1 such as an internal combustion engine in driving engagement with an air compressor 2, a fuel compressor 3 and a water pump 4.

The air compressor 2 has an inlet line 5 connected to any suitable source of air, not shown, and the fuel compressor is connected by a fuel inlet line 6 to any suitable source of fuel, also not shown. Each of said compressors 2 and 3, are in turn connected by their respective discharge lines 7 and 8 to a combustion chamber generally designated 9.

The combustion chamber also communicates with the discharge of the water pump 4 through its discharge line 10, the pump taking its suction through suction line 11 which is connected to a feedwater preheater 12 in turn connected through connecting line 13 to the outlet for the cooling system of the prime mover 1. The feedwater preheater 12 is provided with an inlet line 14 which is connected to any suitable source of feed water not shown and a cooling water outlet 15 connects to the cooling water inlet 16 in any suitable manner as is well known in the art so that cooling water will be automatically

circulated through the feedwater preheater to preheat the feedwater delivered to the water pump 4.

The combustion chamber 9 is shown and described in more detail in the co-pending application Ser. No. 271,512 filed February 14, 1952, now Patent No. 2,734,578, and hence is not described more fully herein.

In operation, air and gas are fed into the ignition area 18 of the combustion chamber 9 and are ignited while the preheated feedwater is circulated through a water jacket 17 about this ignition area 18. The quantity of feedwater delivered to the combustion chamber regulates the temperature of the combusting gases in the ignition area of the combustion chamber and in turn absorbs sufficient heat from this combustion to change the feedwater into steam. This steam is admixed with the combustion chamber to form a mixture consisting of combustion gases and superheated steam with varying amounts of excess air delivered to the combustion chamber so that the total oxygen in the mixture exhausting from the combustion chamber is in excess of 6 percent by weight of the mixture but preferably between 9 and 15 percent by weight of the mixture.

The amount of gas which will be delivered to the combustion chamber may be regulated by a suitable throttle or control valve 19 and the quantity of feedwater delivered to the combustion chamber by a variable speed drive generally designated 20.

The mixture of combustion gases, superheated steam and oxygen pass from the combustion chamber 9 to the main discharge line 21 connected with the casing 22 of an inlet well A for the oil bearing formation generally designated B where the mixture is utilized to heat and drive the residual oil in the oil bearing formation to the producing well generally designated C as above described. The recovered oil will be removed from the producing well in any suitable manner as is well known in the art.

In order to avoid any loss of heat from the fuel utilized in the prime mover 1 the exhaust gases are also passed by an exhaust line 23 through a waste heat boiler 24 where the exhaust gases pass in heat exchange relation with a suitable portion of feedwater delivered through inlet line 25 connected to any suitable source of feedwater, not shown, and the steam developed by the heat exchange relation will pass out of the waste heat boiler through waste heat boiler discharge line 26 connected to the main or common duct 21 where it combines with the mixture of combustion gases, superheated steam and oxygen being delivered to the input well A. A check valve 27 will prevent back pressure from forcing the mixture of combustion gases, superheated steam and free oxygen into the waste heat boiler if the temperature and pressure of the steam delivered from the waste heat boiler reduces below that of the pressure and temperature of the mixture delivered from the combustion chamber.

Apparatus for superheated steam and compressed air mixture

Figure 2 illustrates an apparatus for providing a superheated steam and compressed air mixture which includes a prime mover 30 such as an internal combustion engine which is in driving engagement with an air compressor 31 having its inlet connected to any suitable source of air not shown and its discharge 32 connected to the main or common duct 33 leading to the inlet well casing 34 of the inlet oil generally designated A' for the oil bearing formation.

The cooling system of the prime mover 30 has its inlet connected to a source of feedwater, not shown, and its outlet connected by connecting line 36 to a waste heat boiler 37 which in turn has its outlet 38 communicating with the main or common duct 33. A control or regulating valve 39 being utilized to regulate the amount of steam delivered through the outlet line 38 to the main or common duct 33 connected to the casing 34 of the inlet well A. A by-pass line 40 and valve 41 will regu-

late the flow of heated cooling water to the waste heat boiler 37 from the prime mover. The prime mover 30, in addition, has its exhaust exhausting through exhaust line 42 through the waste heat boiler whereby the exhaust gases pass in heat exchange relationship with the preheated feed water delivered to the waste heat boiler to change the feedwater into the superheated steam required for the mixture delivered to the input well A.

The quantity of superheated steam added to the compressed air will regulate the proportions of the mixture delivered to the main or common duct 33. This is accomplished by regulating the by-pass to deliver the portion of preheated feedwater to the waste heat boiler and by the regulating valve 39 in the discharge line from the waste heat boiler which communicates with the main or common duct 33. The mixture will of course be regulated within the respective desired percentages of 30 to 70 percent by weight of the mixture as above described, dependent in all instances on the stage of oil recovery which is under way.

Modified apparatus for supplying steam and compressed air mixture

Figure 3 shows diagrammatically apparatus in which the primary source of heat is obtained from a conventional high pressure boiler generally designated 50 which may be gas, oil, or electrically operated depending on the local fuel conditions which are most economical.

The boiler 50 connects with an expansion turbine 51 in turn in driving engagement with an air compressor 52.

The air compressor has an inlet line 53 communicating with atmosphere as its source of air and a compressed air discharge line 54 which communicates with the main or common duct 55 in turn connected to the casing 56 of the input well generally designated A".

The air compressor is cooled by the feedwater which will become the steam delivered to the input well A". Thus, the cooling system of the compressor has its inlet connected by feedwater inlet line 57 communicating with any reliable source of feedwater and its outlet discharging through air compressor discharge line 58 which is connected to the inlet of a feedwater heater 59. The outlet of the feedwater heater 59 is connected through connecting line 60 to the inlet for the boiler 50 where the preheated feedwater will have its temperature and pressure raised by heat delivered from a burner 61 receiving fuel from any suitable source, not shown, to provide the desired superheated steam for the steam and compressed gas mixture as hereinafter described.

The superheated steam is discharged through the boiler discharge line 62 to the expansion turbine 51 and after expanding through the turbine to provide the necessary energy for driving the compressor 52 will exhaust through the turbine discharge line 63 to the main or common duct 55, a portion of the steam being by-passed through the feedwater by-pass line 64 back to the feedwater heater 59 for heat exchange relation with the preheated feedwater from the compressor.

A regulating valve 65 is provided to control the percentage of steam delivered and the percentage of steam by-passed so that the desired percentages of superheated steam and compressed air delivered to the main or common duct 55 will be in accordance with the method of oil recovery as above described, depending of course on the particular stage of recovery.

In the event it appears advantageous initially, the expansion turbine can be idled or taken out of operation and superheated steam alone delivered by means of the boiler by-pass line 66 connected between the boiler discharge lines 62 and the main or common duct 55. A valve 67 in the boiler by-pass line and a valve 68 in the boiler discharge line, respectively controlling the quantity of steam delivered directly to the inlet well A" and to the expansion turbine. It is believed clear that initially it would be preferable to deliver superheated steam alone to the inlet well for the heating stage of

oil recovery and thereafter only utilize the expansion turbine for driving the air compressor when the desired conditions about the inlet well A" for "in situ" reaction have been attained.

It will be understood that the invention is not to be limited to the specific construction or arrangement of parts shown but that they may be widely modified within the invention defined by the claims.

What is claimed is:

1. The method of recovering oil from an oil bearing formation having at least one input well and a producing well therein in spaced relation to each other which consists in generating at the surface above said oil bearing formation a heat carrying and driving medium at pressures lower than the separation pressure of the overburden and temperatures between 400° F. and 800° F. and having a composition including superheated steam between 30 and 50 percent by weight of the medium and oxygen in excess of 6 percent by weight of the medium, continuously injecting said medium down said input well to progressively drive residual oil in said formation towards said producing well and to simultaneously and progressively heat said formation between said input well and said producing well between 400° F. to 800° F. until an exothermic reaction will occur between oxygen and hydrocarbon matter in said heated portions to deliver additional heat to said heat carrying and driving medium, and recovering oil from said producing well.

2. The method of oil recovery as claimed in claim 1 wherein said heat carrying and driving medium includes combustion gases, superheated steam and free oxygen in the proportions of steam 30 to 40 percent by weight of the medium, free oxygen 6 to 15 percent by weight of the medium and combustion gases and nitrogen the remaining percentages.

3. The method of oil recover as claimed in claim 1 wherein said heat carrying and driving medium includes superheated steam and compressed air in the proportions of superheated steam 30 to 70 percent by weight of the medium and compressed air 70 to 30 percent by weight of the medium, the free oxygen content of the medium at all times to exceed 6 percent by weight of the medium.

4. The method of recovering oil from an oil bearing formation having at least one input well and a producing well therein in spaced relation to each other which consists in compressing gas fuel and air, passing the gas fuel and an excess of air at high pressures to a combustion chamber at the surface above said oil bearing formation, passing cooling water to the combustion chamber to control the temperature thereof, generating in said combustion chamber a heat carrying and driving medium at pressures lower than the separation pressure of the overburden and temperatures between 400° F. and 800° F. by combusting the fuel gas and air in the combustion chamber and admixing therewith steam formed from the cooling water utilized to control the temperature of said combustion chamber to form a composition including superheated steam between 30 and 50 percent by weight of the medium and having oxygen in excess of 6 percent by weight of the medium, continuously injecting said medium down said input well to progressively drive residual oil in said formation towards said producing well and to simultaneously and progressively heat said formation between said input well and said producing well between 400° F. to 800° F. until an exothermic reaction will occur between oxygen and hydrocarbon matter in said heated portions to deliver additional heat to said heat carrying and driving medium, and recovering oil from said producing well.

5. The method as claimed in claim 4 including the step of recovering the waste heat from the compression of fuel gas and air by heat exchange relation with the cooling water before it is passed to said combustion chamber.

6. The method of recovering oil from an oil bearing formation having at least one input well and a

well therein in spaced relation to each other which consists in generating superheated steam and passing it continuously down the input well as a heating medium, compressing air after the injection of steam down the input well has been instituted and continuously adding it to the steam to form a heat carrying and driving medium, regulating the heat carrying and driving medium at pressures lower than the separation pressure of the overburden and at temperatures between 400° F. and 800° F. and providing a composition in the proportions of superheated steam between 30 and 70 percent by weight of the medium and oxygen in excess of 6 percent by weight of the medium, continuously injecting said medium down said input well to progressively drive residual oil in said formation towards said producing well and to simultaneously and progressively heat said formation between said input well and said producing well between 400° F. and 800° F. until an exothermic reaction will occur between oxygen and hydrocarbon matter in said heated portions

to delivery additional heat to said heat carrying and driving medium, and recovering oil from said producing well.

7. The method as claimed in claim 6 wherein waste heat from the step of compressing the air is recovered by heat exchange with the feedwater from which the superheated steam is generated.

8. The method as claimed in claim 6 wherein heat is recovered from the process of generating the superheated steam.

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