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PREVENTING EXPLOSIONS IN BORE HOLES DURING UNDERGROUND
COMBUSTION OPERATIONS FOR OIL RECOVERY

Filed May 12, 1955

2 Sheets-Sheet 1

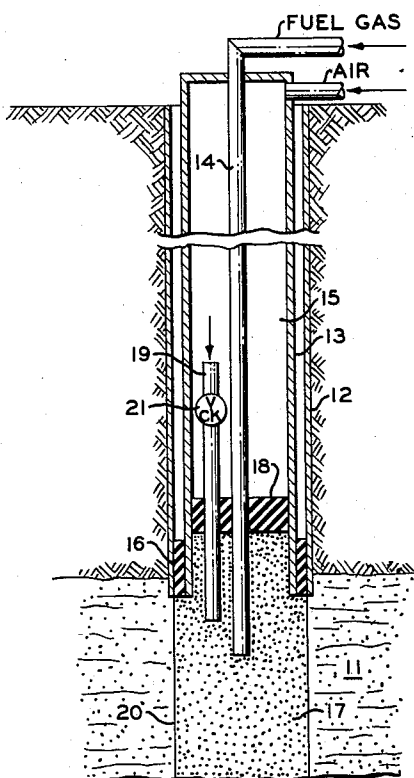


FIG. 1

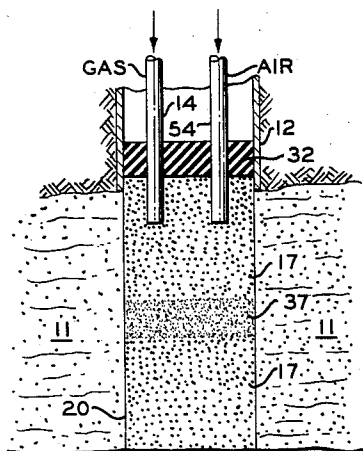


FIG. 2

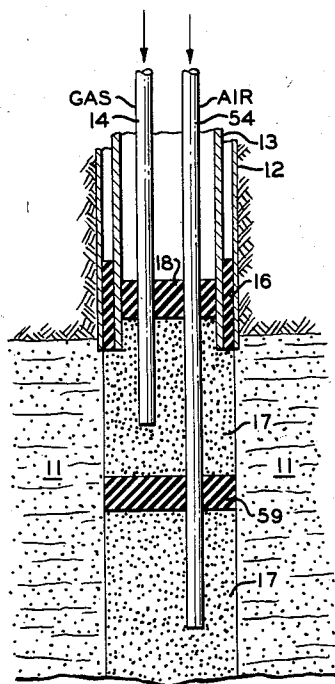


FIG. 3

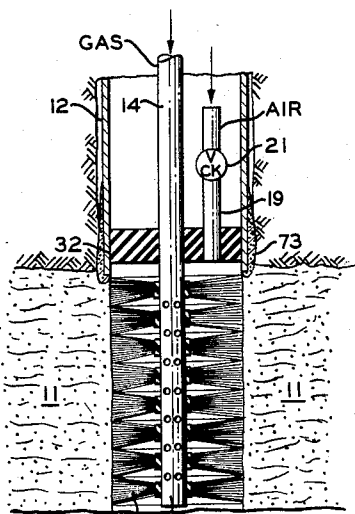


FIG. 4

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2 Sheets-Sheet 2

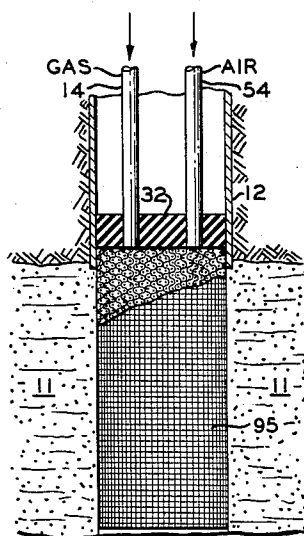


FIG. 5

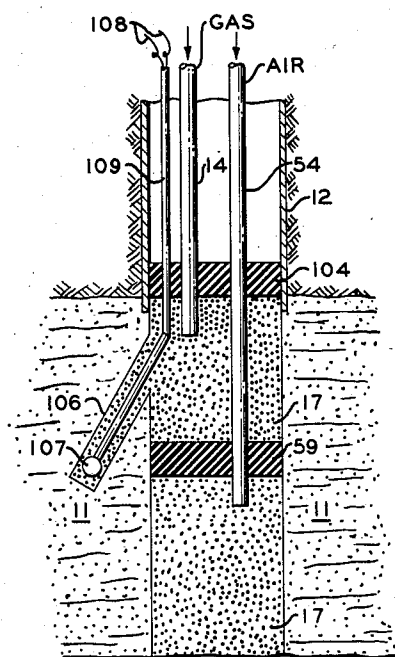


FIG. 6

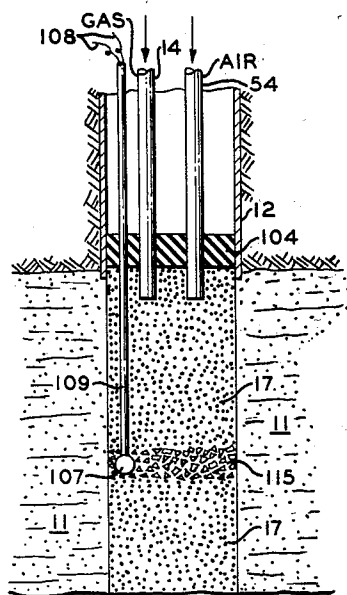


FIG. 7

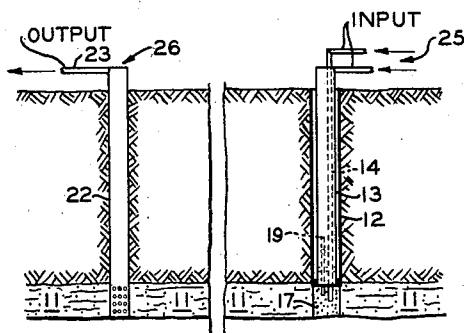


FIG. 8

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PREVENTING EXPLOSIONS IN BORE HOLES DURING UNDERGROUND COMBUSTION OPERATIONS FOR OIL RECOVERY**Francis W. Crawford, Bartlesville, Okla., assignor to Phillips Petroleum Company, a corporation of Delaware****Application May 12, 1955, Serial No. 507,898****12 Claims. (Cl. 166—11)**

This invention relates to a method and apparatus for eliminating the explosive hazard of combustible mixtures encountered in underground combustion operations for the recovery of oil. In one aspect it relates to a method and apparatus for eliminating the explosive hazard of combustible mixtures encountered in input wells in underground combustion operations for the recovery of oil.

It is known that a hazard exists in conducting underground combustion operations for the recovery of oil when mixtures of oxygen and fuel gas in explosive proportions accumulate in the bore of the injection well. When explosive gas mixtures are formed in a well, they sometimes extend the entire distance from the combustion zone to the well head. To carry out certain types of underground combustion operations for oil recovery, it is necessary to inject explosive mixtures of air and fuel gas into the oil containing formation and to burn the fuel therein. The fuel gas and air are preferably conducted down the well separately, as for example, through separate pipes, or the fuel gas is passed down a tubing and the air is passed down in the annulus between the tubing and well casing and then the air and fuel are injected into the reservoir to mix and to burn. When the air and fuel gas injections are stopped, or if injection well pressure is greatly reduced, components of the mixtures in the well bore, especially in the portion near the hot, oil bearing formation, are sometimes present in explosive proportions. In such cases hazards exist in that explosion can very easily occur causing rupture of the well casing and necessitating clean out jobs or even resulting in loss of the well.

An object of my invention is to provide a method for eliminating explosive hazards in heat input wells in underground combustion operations for the recovery of oil.

Another object of my invention is to provide a relatively simple, inexpensive, and easily operable method for eliminating explosive hazards in heat input wells in underground combustion operations for the recovery of oil.

Yet another object of my invention is to provide for the elimination of conditions conducive to the accumulation of explosive gas mixtures in input wells utilized in underground combustion operations for the recovery of oil.

Still other objects and advantages of my invention will be realized upon reading the following description, which taken with the attached drawing, forms a part of this specification.

I accomplish these and other objects and advantages by providing granular packing material in the bore hole adjacent the oil containing formation to prevent accumulation of explosive mixtures at this point. I also provide a well packer immediately above the granular packing material to prevent accumulation of explosive gas mixtures in the tubing or casing above the combustion zone. My invention is ordinarily practiced subsequent to ignition of the fuel gas and/or hydrocarbon in the reservoir and at a time when the combustion zone has ad-

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vanced at least a short distance into the oil bearing reservoir. Under some conditions I position a combustion catalyst approximately midway vertically of the body of granular packing material to make certain that combustion is continuously maintained. When desired, an electrical operated igniter can also be employed. An alternate arrangement involves placing a packer in the well casing about midway vertically of the oil containing formation which is to be heated, with granular packing above and below this packer. In this manner combustible fuel gas admitted to the packing filled space below the packer and air in the packing filled space above the packer do not mix until they have penetrated the formation. The granular packing material is pervious to permit passage of gases therethrough at least as easily as the oil bearing strata in the vicinity of the well bore, and this permeable packing includes, in addition to such material as sand, gravel, chert, vermiculite, refractory ceramic, broken fire brick, pebbles, consolidated particles of clay or crushed pumice, and the like, one or more brush type packers which substantially fills the space in which an explosive mixture is sometimes present.

In the drawing, Figure 1 illustrates diagrammatically, partly in elevation and partly in section, one embodiment of my invention.

Figures 2, 3, 4, 5, 6 and 7 illustrate diagrammatically, partly in elevation and partly in section, still other embodiments of my invention.

Figure 8 illustrates diagrammatically, an arrangement of input and output wells for carrying out my invention.

Referring now to the drawing and specifically to Figure 1, reference numeral 11 identifies an oil bearing formation which it is desired to heat for oil recovery purposes. A bore hole provided with a casing 12 extends from the ground level into the formation 11. Within the casing 12 are disposed tubings 13 and 14 as shown. A packer 16 seals an annulus between casing 12 and tubing 13, packer 18 containing a tube 19 with a check valve 21 seals annulus 15 against upward passage of gas. Below packers 16 and 18 is disposed a mass of particulate or granular material 17 in direct contact with the borehole walls 20 in the formation 11. If desired, casing 12 can be extended on downward from its positioning in Figure 1 to the bottom of the bore hole and the portion of the casing adjacent the walls 20 then being perforated to permit passage of gas or gases from the body of granular material 17 into the oil bearing formation.

In the embodiment illustrated in Figure 1, if desired, the granular material is dropped down the large tubing 13, after which operation the small tubing 14 is run and the packer 18 set. Another alternative is to drop the granular material down the tubing 14 after this tubing is run and the packer 18 with tube 19 is set. In this latter case, it is preferable to make sure that the lower end of tubing 14 is substantially flush with the lower surface of packer 18 so that the entire cavity below this packer is filled with the granular material, said granular material being suitably pervious.

In this manner it is seen that there is no bulk volume in the well at a point near the oil bearing formation in which an appreciable volume of gas can accumulate. The combustible gas injected through tubing 14 is ignited by any suitable means, as by an electrical igniter, or dynamite cap. A percussion cap can also be used to ignite the gas before packer 18 is set.

The granular material which fills the bore hole adjacent the oil containing formation is such a noncombustible material as will withstand temperatures of 500° to 1000° F. without deterioration, and includes such material as sand, gravel, chat, vermiculite, refractory ce-

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ramic, broken fire brick, pumice or stone, pebbles, consolidated particles of clay, or many other heat resistant materials. The particles have a maximum diameter of about $\frac{3}{8}$ inch, the lower limit of size being such that the packing material will have at least the same porosity as the oil bearing formation.

The check valve 21 in tube 19 prevents gas from back flowing up the casing. Thus such a packing material will prevent accumulation of hazardous explosive mixtures because there is no bulk volume of drill hole adjacent the oil bearing formation in which such gases can accumulate.

The packers illustrated in the drawing can be of rubber, or of other and noncombustible material because they must be able to withstand temperatures anticipated in the region in which flame propagation is carried out.

If desired, my invention is carried out after ignition of hydrocarbon fuel in an oil bearing reservoir and at a time when the combustion zone has propagated a short distance into the reservoir. By previously providing a suitable Christmas tree arrangement of valves, etc., the granular material, packer, etc., are lowered into position after combustion has already been started.

In Figure 2 of the drawing a casing 12 extends from the ground level, not shown, to the approximate level of oil bearing formation 11. Granular material 17 is positioned in the well to fill the borehole in the lower portion of the formation 11. On top of this first added granular material is disposed a small layer of a combustion promoting catalyst 37, such as Hopcalite, the use of which is described in U.S. Patent 2,382,471. On top of this layer of catalyst is disposed another layer of the granular material 17 to fill the borehole up to at least the top of the oil bearing formation 11. Two strings of tubing 14 and 54 are run and a packer 32 is installed as illustrated. The beds of the granular material 17 in this embodiment are in direct contact with the walls 20 of the oil bearing formation 11, or if desired, casing 12 is extended downward from the position illustrated. In this latter case, the casing adjacent the walls 20 of the formation is obviously perforated.

In Figure 3 are lower and upper beds of granular material 17 as in Figure 2, but they are separated by a packer 59. The borehole contains a casing 12 down to about the top of the packing 17 (and formation 11), or if desired the casing is run to the bottom of the oil bearing formation. In this latter case the casing is perforated to permit inflow or outflow of fluid from the borehole. A large diameter tubing 13 is run into the well and sealed to the casing 12 by a packer 16. Within the large diameter tubing 13 are placed the smaller tubings 14 and 54, which extend through a packer 18 as shown. Tubing 14 is for fuel gas and tubing 54 for air. The packer 59 is intended to maintain the air and fuel gas separate until they are pressured into the formation. That is, the air and fuel gas are injected separately into the formation and combustion takes place only at such a time and location at which the fuel and air come into contact.

In Figure 4, the structure and operation is substantially the same as in Figure 1 except that in place of granular packing material being used to fill the bulk volume of the borehole within the oil bearing formation, a brush packer or packers are used. Thus, brush packers 80 are disposed on an extension 81 of tubing 14 in the portion of the borehole within the oil bearing formation. This tubing extension serves the dual purpose of conducting fuel to the space below packer 32 and as a support for the brush packing 80. Tube 19 fitted with check valve 21, in packer 32 allows passage of air for combustion of the fuel gas without permitting back flow. A casing 12 is disposed in a conventional manner in the borehole, and is cemented at 73 to the walls thereof. Air and fuel gas, and/or hot combustion gases are injected from the general area of the brush packers 80 into the oil bearing formation 11. When brush packing is used, the brush ma-

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terial is made of metal fibers or wire which are capable of withstanding high temperatures, that is temperatures in the region of 500° to 1000° F. Stainless steel wire, and tungsten wire are satisfactory brush material. The check valve 21 in tube 19 in packer 32 prevents back flow of gas.

In Figure 5, a casing 12 lines the borehole down to approximately the oil bearing formation 11. A tightly rolled spiral of wire screening 95 fills the borehole within the oil bearing formation. This wire screening is intended to possess a porosity at least as great as the adjacent oil bearing formation. Immediately above the roll of screen 95 a packer 32 is set to seal off that portion of the borehole containing the screen from the upper open hole. Tubes 14 and 54 extend from above ground through the packer to the screen-containing volume for passage of fuel gas and air, respectively, therinto.

The embodiment illustrated in Figure 6 is similar, in general, to that illustrated in Figure 3 with the exception that provision is made for igniting the fuel gas in starting the combustion operation. Casing 12 lines the borehole down to approximately the oil bearing formation 11. Upper and lower beds of granular packing material 17 are separated by packer 59. Packer 104 is set to seal the upper bed of granular material 17 from the upper open hole. A side extension 106 containing an igniter 107 is provided extending outward from the bore hole as shown. The volume of the side extension not occupied by the igniter is filled with granular material 17. Wires 108, enclosed in conduit 109, lead from the igniter to the ground level and to a source of electrical current, not shown. Tubes 14 and 54 extend from above ground to the separate layers of granular material 17 as shown, for passage of gas and air, respectively, as indicated. In the operation of this embodiment of my invention, gas fills the voids in the upper bed of packing material 17 including side extension 106. When air from the voids in the lower bed of the packing material flows through the formation 11 and enters the side extension space 106, the igniter 107 operates to start the combustion operation. By employing an igniter positioned as illustrated in Figure 6, I am able to start combustion at a point in the oil bearing formation at a predetermined distance from the bore hole, and to maintain it within the formation.

The embodiment illustrated in Figure 7 is more or less similar to that illustrated in Figure 1, excepting provision is made for starting the combustion operation after placement of the granular packing material 17, packer 104, etc. Casing 12 lines the borehole down to approximately the top level of the oil bearing formation 11. Beds of granular packing material 17 are provided as shown and are separated by a layer of coarse gravel 115 to serve as an ignition zone. Igniter 107, having wires 108 attached thereto and extending to above ground, is provided for starting the combustion. Preferably, wires 108 are encased in a conduit 109. A packer 104 is set on top of the packing 17. Tubings 14 and 54 are disposed through packer 104, as shown, and extend to above ground for admission of fuel gas and air, respectively. In this embodiment, the voids in the coarse gravel are greater than in the beds of granular material 17. By this means it is intended that combustion take place within the coarse gravel and not within the beds of granular material 17. Hot gases of combustion enter the oil bearing formation 11 from the immediate vicinity of gravel 115.

When employing the embodiments of my invention illustrated in Figures 1, 3, 4, and 5, the combustion is started and when it has progressed at least a short distance into the oil bearing formation the granular packing material, the brush packers or roll of screen, and packer or packers are introduced into the well. This procedure is easily carried out by use of a suitable arrangement of Christmas tree valves, etc., without shutting down the combustion operation.

The novelty of my invention resides in the use of granular packing material such as sand, gravel, chert, vermiculite, refractory ceramic, broken fire brick, pebbles, consolidated clay and pumice, in the bore hole adjacent the oil bearing formation to prevent accumulation of explosive mixtures within the bore hole during the underground combustion operations for recovery of oil. A packer is used above and adjacent the packing material to prevent accumulation of explosive gases in the open hole above the packing material.

The packer or packers illustrated in the drawings can be of rubber, or of other material, but must be able to withstand temperatures anticipated in the underground combustion operations. Such materials as cement, asbestos material, fiber asbestos or refractory cement can be used as gas-tight packing around the tubes, in place of or in conjunction with the packers, to prevent upward passage of combustible gases into the open hole above the combustion zone. The cement, or refractory cement can be in finely ground dry powder form or as a slurry, when used as a slurry it is preferable to set a conventional packer on the porous granular material and then add the slurry.

The region adjacent the oil bearing zone heated by combustion is filled with inert, combustion resistant packing material as herein disclosed. When a granular material is used it should be no larger than about $\frac{3}{8}$ inch in diameter and the lower limit of particle size is such that the packing material in place will be at least as porous as the oil bearing formulation. Granular packing material as disclosed herein is satisfactory for my purpose. Likewise more or less conventional brush packers are used provided the wires of the brush are of material capable of withstanding the operating temperatures and providing the relative volume of the wires is such as to provide about the same limits of porosity as given above relative to the use of granular material.

According to my invention there is no bulk volume for accumulation of explosive mixtures of gases in portions of the input well adjacent the oil-bearing formation. A packer or plug is sealed in the well adjacent the top of the porous filling or packing material so that fuel gas cannot pass upward to be mixed with air. In cases where air for promoting combustion is pumped downward in the annulus between a tubing and the casing it is preferable to seal off the annulus from the porous filling material with a packer provided with a tube containing a check valve for passage of the air from the annulus to the filling material.

The electrical wires 108 of Figures 6 and 7 extend to the ground surface and are connected to a battery or other type of suitable firing mechanism. A dynamite cap or percussion cap can, if desired, be dropped into the well through the casing head by utilizing a suitable pressure valve or air lock at the well head for starting ignition after which my packing material is installed as herein disclosed.

In Figure 8 is illustrated an arrangement of wells containing at least one input well 25 and at least one output well 26. Fuel gas and air are passed down tubings 14 and 13, respectively, the gas being burned with the free oxygen content of the air within the granular material 17 and/or within the oil bearing formation 11. Production hydrocarbons find their way to an output well 26 provided with a casing 22 as far down as the oil bearing formation. The produced hydrocarbons are conducted from the head of the casing 22 in the output well 26 through a pipe 23 for subsequent treatment, or such disposal as desired.

While certain embodiments of the invention have been described for illustrative purposes, the invention obviously is not limited thereto.

I claim:

1. In an operation for recovery of petroleum hydrocarbons from an oil bearing formation by heating the formation by combustion of fuel gas with air, wherein said

oil bearing formation is in communication with an inlet well for inlet of said fuel gas and air for supporting combustion thereof and an outlet well for recovery of said petroleum hydrocarbons, a method for maintaining said input well free from explosive hazard during said operation, comprising, introducing a first quantity of a packing material resistant to combustion into said input well adjacent said oil bearing formation, setting a first gas-tight packer above and adjacent said first quantity of packing material, introducing a second quantity of packing material into said input well above and adjacent said first gas-tight packer, setting a second gas-tight packer above and adjacent said second quantity of packing material, the combined heights of said first and second quantities of packing material being such that said packing material extends from the well bottom to at least the top level of said oil-bearing formation, a first tubing extending from said second quantity of packing material through said second packer to above ground for introduction of one of said fuel gas and air into said second quantity of packing material, a second tubing extending from said first quantity of packing material through said packers and said second quantity of packing material to above ground for introduction of the other of said fuel gas and air into said first quantity of packing material, said quantities of packing material being at least as porous as said oil bearing formation, passing said fuel gas and air through said tubings into said input well and burning said fuel gas with said air in said formation and recovering hydrocarbons from said outlet well.

2. Apparatus adapted to be installed in a borehole extending into an oil-bearing formation comprising, in combination, a casing in said borehole extending from above ground only to the top of said oil-bearing formation, a noncombustible pervious material substantially filling the borehole in said formation, said pervious material being in contact with said oil bearing formation, a combustion initiating catalyst disposed in said noncombustible pervious material intermediate the top and bottom thereof, a packer adjacent the top of said pervious material sealing the portion of the borehole containing said pervious material from the upper and remaining portion of the borehole, a first tubing extending through said packer for introducing a fuel gas below said packer and into said pervious material and a second tubing extending through said packer for introducing air below said packer and into said pervious material.

3. The apparatus of claim 2 wherein said pervious material is gravel.

4. Apparatus which avoids explosion hazard in a well wherein a combustible mixture of gases is burned comprising, in combination, a well penetrating a hydrocarbon-bearing formation, a casing in said well extending downward from ground level and terminating above said formation and being closed at its upper end, a mass of solid, particulate, noncombustible, heat refractory filling material filling said well to a level adjacent the top of said formation, said material being in direct contact with said formation, a packer across said well on top of said filling material thereby avoiding open hole below said packer, conduit means extending through said packer for introducing an oxygen-containing gas and a fuel gas into said filling material and means for igniting said fuel gas within said filling material.

5. The apparatus of claim 4 wherein said filling material is gravel.

6. The apparatus of claim 4 wherein said filling material is metal fibers.

7. The apparatus of claim 4 wherein said means for igniting said fuel gas is a combustion initiating catalyst.

8. The apparatus of claim 4 wherein said means for igniting said fuel gas is an electrical means.

9. Apparatus which avoids explosive hazard in a well wherein a combustible mixture of gases is burned comprising, in combination, a well penetrating a hydrocarbon-

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bearing formation, a casing in said well extending downward from ground level and terminating above said formation and being closed at its upper end, a first mass of solid, particulate, noncombustible, heat refractory filling material in said well filling the well in the lower portion of said formation, a first packer across said well on top of said filling material, a second mass of said filling material filling said well from said packer to a level adjacent the top of said formation, a second packer across said well on top of the second mass of filling material, the packers being disposed on the tops of the respective masses of filling material so as to avoid open hole below the packers, said masses of filling material being in direct contact with said formation, conduit means for introducing fuel gas to one of said masses of filling material and for introducing an oxygen-containing gas to the other, and means for igniting said fuel gas in said formation.

10. The apparatus of claim 9 wherein the masses of filling material are gravel.

11. A process for producing hydrocarbons from a permeable subterranean formation containing hydrocarbons which comprises packing an input well in said formation with a noncombustible particulate refractory filling material up to the top of said formation in such a manner that said filling material is in direct contact with the formation containing hydrocarbons, said input well being uncased within said formation, packing off said input well adjacent the top of said filling material so as to confine the hereinafter injected fuel gas and oxygen-containing gas to the packed area of the well, injecting a fuel gas and an oxygen-containing gas directly into said filling material, igniting and burning said fuel gas in the free space between the particles of filling material so as to heat said particles and to produce hot combustion gas, continuing the injection of said oxygen-containing gas and said fuel gas and continuing said burning so as to force hot combustion gas into said formation where-by hydrocarbons therein are heated and driven from said

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formation into an output well in admixture with said combustion gas and recovering said hydrocarbons and combustion gas from said output well.

12. A process for producing hydrocarbons from a permeable subterranean hydrocarbon containing formation which comprises packing an input well penetrating said formation with a first body of a noncombustible particulate heat refractory filling material, packing off said input well adjacent the top of said first body of filling material so as to confine hereinafter injected gas, further packing said input well with a second body of said filling material, packing off said input well adjacent the top of said second body of filling material so as to confine hereinafter injected gas, the second body of filling material extending up to the top of said formation, injecting a fuel gas into one of the bodies of filling material and subsequently into the formation, injecting an oxygen-containing gas into the other of said bodies of filling material and subsequently into the formation and into contact with said fuel gas, igniting and burning said fuel gas in the free space of said permeable formation, the burning being supported by said oxygen-containing gas thereby producing hot combustion gas, continuing injection of said oxygen-containing gas and said fuel gas and continuing said burning thereby forcing hot combustion gas through said formation whereby hydrocarbons in said formation are heated and driven in admixture with said combustion gas into an output well and recovering said hydrocarbon from said output well.

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