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[54] METHOD FOR STRENGTHENING RESERVOIR FRACTURES
9 Claims, 1 Drawing Fig.

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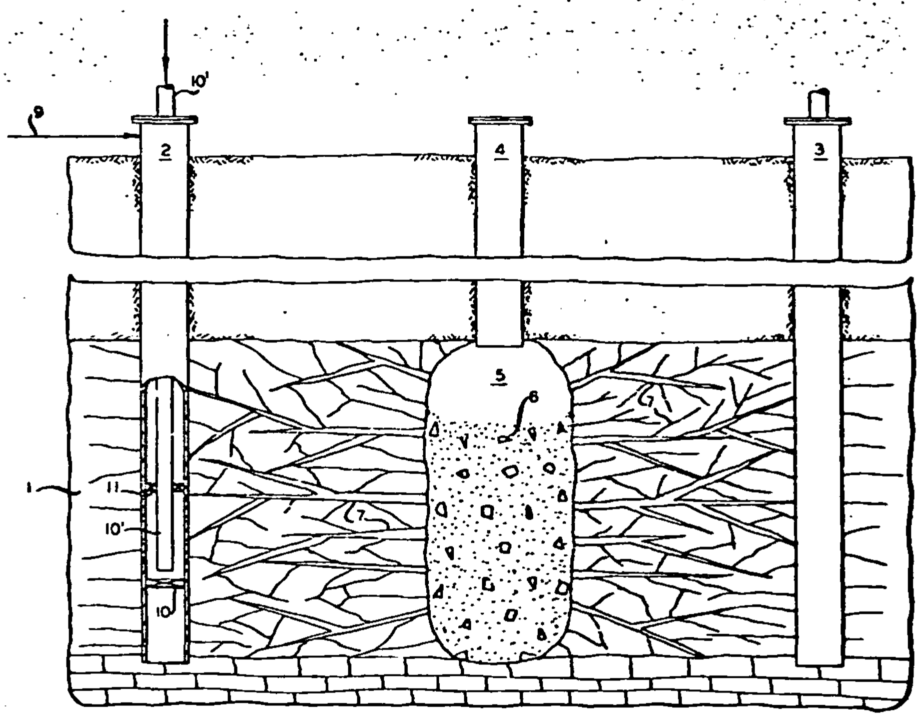
ABSTRACT: Hydrocarbons are produced from hydrocarbon bearing formations, including oil shale, in situ through fractures communicating with production wells by injecting combustion supporting materials such as an oxygen-containing gas substantially completely throughout the fractures and then initiating in situ combustion (supported by the injected gas) at an extremity of the fractures prescribed by either injection or production wells or a subterranean detonation zone or cavity and directing the resultant in situ combustion front along the axis of the fractures and maintaining combustion at a level sufficient to fuse the formation adjacent the fractures whereby the resistance of the fractures to collapse under compressive stress is increased. Collapse of fractures treated in this manner under the influence of formation expansion promoted by subsequent temperature elevation accompanying retorting is substantially retarded. Therefore the strengthened fractures can be employed to facilitate heat transfer throughout the formation.



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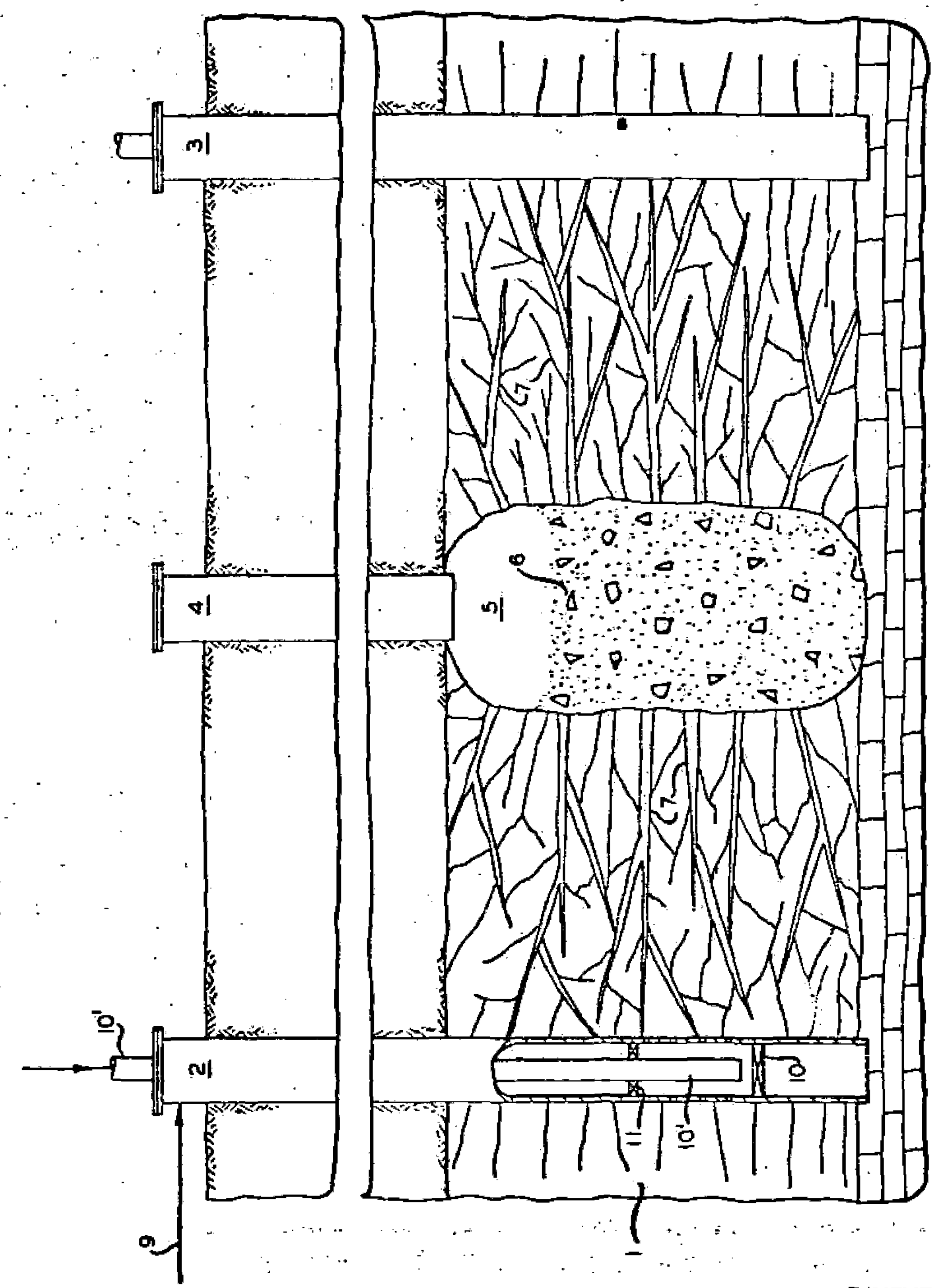

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METHOD FOR STRENGTHENING RESERVOIR FRACTURES

BACKGROUND OF THE INVENTION

This invention relates to a process for the in situ production of oil from oil shale by pyrolysis with hot gases. In accordance with another aspect, this invention relates to an improved method of obtaining oil from oil shale around a nuclear produced chimney by burning the fractures therethrough in an oxygen-enriched atmosphere, and thereafter producing the formation by the use of hot inert gases.

Tremendous deposits of oil shales occur in Colorado, Utah, and Wyoming, and various petroleum companies and the federal government are doing research on methods of producing oil from these deposits. Numerous proposals have been made, including mining the shale and retorting the mined shale above ground and applying heat to the shale in situ with hot gases including oxygen and excluding oxygen. Steam, hot combustion gas, hot air, etc. have been proposed as heating media for the pyrolysis operation.

In situ combustion and in situ retorting by either in situ combustion or injection of heat exchange fluid has been the subject of considerable experimental investigation as means for expediting the secondary recovery and have found commercial application in numerous instances. It is recognized that during the course of these secondary recovery procedures the formation strata is subjected to considerable expansion due to temperature elevation. This expansion generally results in the collapse and termination of relatively unstable communication networks, e.g., fractures, throughout the formation with the result that fluid flow to recovery wells and from injection wells is diminished or deterred by an extent necessitating increased driving forces, i.e., differential pressure between input and production wells. It is quite understandable that this collapse also deters natural drainage of hydrocarbons from retorted formation where the hydrocarbon fluids are not subjected to artificial driving forces.

The utilization of such fluid communication channels is particularly attractive in highly fragmented or fractured formations such as those which result from the subterranean detonation of explosive charges. Although the formation rock in the immediate vicinity of the detonation zone or chimney is fragmented sufficiently to enable ready access or egress of fluids, the adjacent formation is fractured to a lesser extent and generally comprises a relatively unstable network of intercommunicating fractures which are either substantially restricted or completely closed by thermal expansion of the adjacent formation under the influence of elevated temperatures necessary to retort those portions of the hydrocarbon bearing strata. Throughout the specification and claims the term hydrocarbon is intended to include not only compounds of carbon and hydrogen, but also other formation organic matter such as the kerogen contained in oil shale from which hydrocarbons and other substances are formed by heat.

The use of nuclear explosives to fragment underground formations has gained considerable acceptance as an economically feasible method of producing oil and gas from reservoirs having such low original permeability as to be incapable of economic production in the original state. The utilization of nuclear explosives in this regard is described briefly by D. B. Lombard in his article "Recovering Oil from Shale with Nuclear Explosives" published in Aug. 1965, issue of *Journal of Petroleum Technology*, pages 877–882.

By this method a nuclear charge is placed at the desired elevation in a suitable reservoir strata and detonated to produce a cavity containing fragmented reservoir rock, the dimensions of the cavity and the extent of fragmentation depending, of course, upon the magnitude of the detonation and the characteristics of the surrounding formations. For example, Lombard refers to the effects of detonating nuclear charges having energies of from 20 to about 100 kilotons in "hard rock" and indicates that the resulting fragmentation zone, i.e., nuclear chimney, has a diameter of from 100 to several hundred feet and a vertical extent of about 2¼ cavity diameters measured from the point of detonation to the chimney top.

It is further pointed out by Lombard that although the fragmentation zone or nuclear chimney is fairly well defined, that the sidewalls, i.e., the remaining unfragmented formation defining the nuclear chimney, possess numerous fractures extending outwardly in all directions from the sidewalls for a distance of approximately one-half of the diameter of the fragmentation zone. These fractures result in a substantial increase in the permeability of the formation surrounding the fragmentation zone which enable the egress of formation fluids from the fragmentation zone and the strata immediately surrounding the nuclear chimney during subsequent retorting operations and correlary procedures involving the use of elevated temperatures and pressures within the fragmented area.

The degree of fracturing and consequently the degree of permeability which results in those strata defining the outer periphery of the fragmentation zone depends primarily on certain characteristics of the formations, per se, and to some extent on the intensity of the detonation.

It is therefore one object of this invention to provide a method for treating fragmentation zones produced by subterranean detonation.

It is another object of this invention to improve the production of reservoir fluids from fragmentation zones resulting from subterranean detonations.

It is yet another object of this invention to provide a method for treating subterranean nuclear chimneys and fractures resulting therefrom.

It is another object of this invention to provide a method for decreasing the permeability of fractures extending and surrounding nuclear chimneys.

It is yet another object of this invention to improve the ultimate recovery of reservoir fluid from strata fragmented by subterranean detonation.

It is another object of this invention to provide a method for utilizing the heat retained in retorted subterranean fragmentation zones.

SUMMARY OF THE INVENTION

In accordance with the invention, the fractures or channels extending outwardly from the periphery of a fragmentation zone are contacted with an oxygen-containing gas under combustion conditions to form slag channels between the fragmentation zone and input and output wells spaced around the periphery of the fractures extending out from the fragmentation zone.

In accordance with one embodiment of this invention, the fractures extending outwardly from a fragmentation zone are contacted by an oxygen-enriched gas injected through wells drilled into the fractures extending outwardly from the fragmentation zone whereby the fractures are burned outwardly by counterflow combustion to form slag channels. Oil is produced from the formation by passing gases through the fragmentation zone to be heated and then through the channels and up the surrounding wells positioned near the periphery of the fractures.

In accordance with a further embodiment of the invention, to prevent bypassing of some of the fractured channels an inert gas can be injected through some of the fracture channels while others are being burned by an oxygen-enriched gas.

More specifically, in the production of oil shale, a nuclear device is detonated at a sufficient depth to produce an upwardly extending chimney containing Kerogen, which can be retorted under known conditions to produce shale oil. This nuclear detonation also produces fractures in the adjacent strata. This strata normally contain as much shale oil as the chimney, but cannot be produced since normal retorting procedures cause the collapse of the strata adjacent the chimney. Thus, according to this invention, a plurality of peripheral wells are placed at the furtherest extremities of the fractures produced by the nuclear explosion, and then an oxygen-enriched gas is injected into the fractures from the injection wells, producing the combustion of the Kerogen contained within the fractures, commencing adjacent the chimney and proceeding back toward the injection wells, and the molten Kerogen produces a slag that, when cooled, forms a fused lining on the interior of the fractures. The strata in between the nuclear chimney and the peripheral injection wells can now be retorted employing normal techniques and the slag-lined fractures form channels for the production of the oil shale, which will not collapse under the retorting conditions.

The cost of breaking oil shale via nuclear explosives can be cut by a factor of 5 to 10 if the shale which is only fractured can be retorted as well as the shale which is reduced to broken rubble in the detonation zones. The present invention provides a method for preparing flow channels in fractured oil shale which will not heal by thermal expansion and thus allow for more efficient production of oil from the use of a single nuclear device.

Although the method herein described affords advantages when applied to all types of hydrocarbon bearing formations in which it is desired to substantially preserve the integrity of fractures and/or channels within the formation strata, it is particularly advantageous when applied to formations which have been extensively fractured by the detonation of explosive charges. For this reason the method is described with relation to the recovery of oil from strata fractured by such a subterranean detonation.

BRIEF DESCRIPTION OF THE DRAWING

The drawing shows a cross section of a hydrocarbon-bearing formation having a nuclear detonation chimney and accompanying injection and production wells.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Such a formation and accompanying injection and production of wells are illustrated schematically in the drawing wherein hydrocarbon bearing strata 1 is penetrated by wells 2, 3, and 4 is occupied by detonation zone or chimney 5 and outwardly extending fractures 7. Wells 2 and 3 are placed so as to communicate with fractures 7 and thereby indirectly communicate with the nuclear chimney 5 and the intervening strata.

Prior to the treatment of this intervening strata the highly fragmented reservoir rock 6 in nuclear chimney 5 can be retorted by any one of several methods, some of which have already been discussed. For example, the fragmented shale in such chimneys can be retorted by the passage of a flame front from the uppermost portion of the fragmented oil shale downwardly through the entire mass of fragmented rock whereby liberated hydrocarbons flow downwardly through the fragmentation zone and accumulate in the lower extremities thereof. The temperature of the combustion zone is controlled by recycling, for example, 3 to 5 volumes of gas for each volume of air injected. These accumulated hydrocarbons are then preferably produced by means of a production well drilled directionally downwardly and laterally into the lower extremities of the fragmented area. Such production of the accumulated fluids can be accomplished by any conventional means. These methods can be made more efficient by operating at a positive pressure over the accumulated fluid in order to prevent the vaporization thereof by the elevated temperature encountered during shale retorting.

Elevated operating pressures, e.g., 100 to 1,000 p.s.i.a., are desirable in some processes to retort nuclear chimneys such as when hot shale gas is recycled to retort the nuclear chimney to reduce the cost of compressors and wells. One embodiment of the hot shale gas recycle process is described in copending application Ser. No. 641,815. The process of this invention has several advantages when employed in combination with the retorting process described in copending application Ser. No. 639,490 now U.S. Pat. No. 3,490,202: the shale would be preheated and the amount of air necessary to retort the chimney would be reduced.

Following this procedure whereby the fragmented rock 6 within the nuclear chimney is retorted, it is desirable to retort the shale disposed between the outer periphery of the fragmentation zone and the adjacent wells 2 and 3 taking advantage of the fluid communication network defined by the series of fractures 7. However, if the temperature of this adjoining formation is elevated to a point sufficient to retort the formation rock that strata expands due to its thermal coefficient of expansion and plastic deformation characteristics by an amount sufficient to compress and collapse the fractures, thereby destroying the network of fractures from which fluids could otherwise be injected into the formation and through which exuded hydrocarbons could be directed to the production wells 2 and 3. The method of this invention reduces the extent of collapse associated with the elevation of formation temperature by fusing and cooling the fracture sidewalls thereby greatly increasing their resistance to collapse under the influence of compressional forces.

By this procedure an oxidizing material such as air is injected into the fractures through either of the wells 2 or 3 and combustion or formation hydrocarbon is instituted in the formation immediately adjacent the fractures and propagated by the addition of the oxidizing material thereto with the result that the temperature of the formation rock defining the fractures, i.e., the fracture sidewalls, is elevated sufficiently to fuse the same. Following a sufficient degree of burning to accomplish the extent of fusion desired the combustion is terminated by discontinuing the injection of oxidizing gas and the formation sidewalls are allowed to cool to a point below their fusion temperature. It is also preferably to restrict the high temperature fusion zone to the vicinity of the fracture sidewalls. This can be accomplished by judiciously controlling the pressure on the combustion supporting medium at a level sufficient only to force the gas into the fractures and preferably not more than 150 p.s.i. above formation pressure.

In initiating combustion in the strata adjoining the nuclear chimney and in the subsequent retorting of that strata it is desirable to take advantage of the heat stored in the detonation zone by virtue of the previous retorting of that area of the formation. As a result, it is presently preferred to inject the oxidizing material, i.e., air, into injection wells 2 and/or 3 and to force the gas outwardly through the series of fractures 7 to the periphery of the chimney at which point the reservoir is at a temperature sufficient to autoignite the hydrocarbon retained in the strata adjacent the chimney. This temperature should be at least about 600° F. and is usually in the range of from about 750° F. to about 1,000° F. shortly after the termination of retorting procedures employed to produce the hydrocarbon in the chimney 5. Injection of oxidizing gas is continued at a rate sufficient to maintain the in situ combustion of hydrocarbons radially outwardly from the chimney toward the injection well until the burning has progressed to the immediate vicinity of the injection well bore or until the desired degree of fusion along the fracture walls has been achieved.

Air injection rates will, of course, vary considerably depending upon the extent of fracturing and the extent of burning maintained at any given time. However, exemplary of the injection rates that can be employed in such operations are those within the range of about 50,000 to about 100,000 standard cubic feet per hour of atmospheric air. These injection rates are sufficient to maintain a degree of combustion along the fracture of the sidewalls such that the temperature of the sidewalls is elevated to a point above the fusion point of the hydrocarbon-bearing formation. For example, when the formation is oil shale the fracture sidewalls should be elevated to a temperature of at least about 1,400°–2,000° F. to accomplish this purpose. It is also possible by this method to treat selected portions of the fractured strata by sealing off the injection well bore as illustrated in the drawing by means of packers 10 and 11. The oxidizing fluid is then injected by way of pipe 10' to the space intermediate the packers and consequently enters those fractures which communicate with the well bore in the region defined by the packers. During such selective treatment procedures an inert gas can be injected through pipe 9 to prevent airflow and undesired combustion in these areas. Fluids are produced from well bore 4 as desired to control the pressure in the nuclear chimney.

Following this method of preparation the fractured formation can be retorted to recover hydrocarbons by any one of the numerous retorting procedures known to the art several of which have already been discussed. Retorting temperatures are generally within the range of from about 750° to about 1,000° F. and should, of course, be maintained below the fusion point of the formation strata in order that the structural integrity of the formation and the fluid communication network defined by fractures 7 is not destroyed. Steam or nonoxidizing gas injected for this purpose can be passed into the formation as already described by way of the fractures 7 and is preferably introduced through retorted chimney 5, and through the sidewalls of the detonation zone into the adjoining formation to take advantage of the heat stored in the chimney 5. For example, in one embodiment steam or water can be injected by way of well bore 4 into chimney 5 wherein the heat stored in the chimney is transferred to the injected water after which it is passed to the sidewalls of the chimney into fractures 7 for the purpose of elevating the temperature of the intermediate strata.

It is also possible to retort intermediate strata selectively in a manner analogous to that already described in relation to the preparation of the network of fractures. For example, the heating medium can be injected by well bore 4 through chimney 5 into the adjoining fracture network and passed selectively through the lower portion thereof prescribed by the blocked zone in the well bore 2 defined by the position of packers 10 and 11 by blocking outlet 9. For example, the upper portions of the hydrocarbon bearing strata can be retorted in a first stage by blocking exit 10', whereby the heat exchange medium passes through the upper portions of the reservoir.

After this retorting has been terminated the heat contained in that portion of the reservoir can be employed along with the heat contained in the chimney 5 by injecting steam or water both through well bore 4 and opening pipe 10' and/or whereby the steam from the chimney enters the lower portion of the formation through the nuclear chimney wall, passes through the formation by virtue of the intercommunicating network of fractures 7 and into the area of the well bore 2.

SPECIFIC EXAMPLE

A nuclear chimney is formed by a 200 kiloton bomb at a depth of 3,000 feet in an oil shale formation. The resulting nuclear chimney is 420 feet in diameter and 1,000 feet high. Fractures induced by preparation of the nuclear chimney extend outwardly from the center of the nuclear chimney for a distance of 500 to 600 feet.

The ring of 15 wells is drilled concentric to the nuclear chimney with a radius of 500 feet. The wells are cased and cemented. At intervals of 40 feet starting from a position adjacent the top of the nuclear chimney the casing is perforated or cut and packers set so oxygen can be injected. Oxygen is injected at a rate of 80,000 standard cubic feet per hour. When the oxygen injected into the fractures reaches the hot previously retorted nuclear chimney the adjacent oil shale is ignited and burns very intensely, melting the adjacent shale matrix and enlarging the fracture. The combustion zone burns back to the injection well in 5 to 8 hours, resulting in a flow channel propped with molten shale which has solidified. The flow channels are about 2 inches wide and 5 to 10 feet across. This process of forming flow channels is repeated at each 40-foot interval in each of the 15 wells. As a safety precaution, inert gas is injected into the previously formed flow channels. After the flow channels are formed, the shale adjacent the channels is retorted by injection of hot produced shale gases through the chimney which flow through the propped fractures to the surrounding wells to cause heating of the shale around the propped fractures to produce hydrocarbons. The bottom hole temperature of the surrounding wells is maintained at a temperature in the 300°–400° F. range by regulating the flow of gases therefrom at the surface.

I claim:

1. A method of producing a hydrocarbon-bearing shale formation in situ which comprises fracturing said formation, injecting a combustion supporting material into said fractures and burning at least a portion of said hydrocarbon contained in said formation immediately adjacent said fractures at a rate and for a period of time sufficient to elevate the temperature of said formation adjacent said fractures to at least about 1,400° F. to fuse the sidewalls of said fractures thereby increasing the structural resistance of said fractures to compressive forces, retorting said formation to liberate hydrocarbon therefrom and producing the thus liberated hydrocarbon at least partially through said fractures.

2. The method of claim 1 wherein said combustion-supporting material is an oxygen-containing gas.

3. The method of claim 2 wherein said formation further comprises a subterranean nuclear chimney and accompanying radially outwardly extending fractures in communication with at least one injection well bore, and said oxygen containing gas is injected into said fractures through said injection well and passed through said fractures at least to the periphery of said chimney, igniting said hydrocarbon in said sidewalls of said fractures adjacent said chimney and continuing the passage of said oxygen-containing gas into said fractures to direct said combustion radially outwardly from said chimney and axially along said fractures to said injection well and thereby fusing the walls of said fractures.

4. The method of claim 3 wherein the temperature of said chimney is at least about 600° F. and said hydrocarbons are autoignited by contact with said oxygen-containing gas at said temperature.

5. The method of claim 3 wherein the injection pressure of said gas is up to about 150 p.s.i. above the formation pressure adjacent said fractures.

6. The method of claim 3 wherein said chimney is retorted prior to the injection of said oxygen-containing gas via said injection wells and is at a temperature of from about 750° to about 1,000° F.

7. The method of claim 6 further comprising retorting said formation following said fusing of said fractures.

8. The method of claim 7 wherein said formation is retorted by injecting a heating medium into said formation via said chimney and said fractures.

9. The method of claim 8 wherein said heating medium is steam produced at a temperature of from about 750° to about 1,000° F. by injecting one of steam and water into said detonation zone to heat the same via an injection well communicating with said chimney.

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