

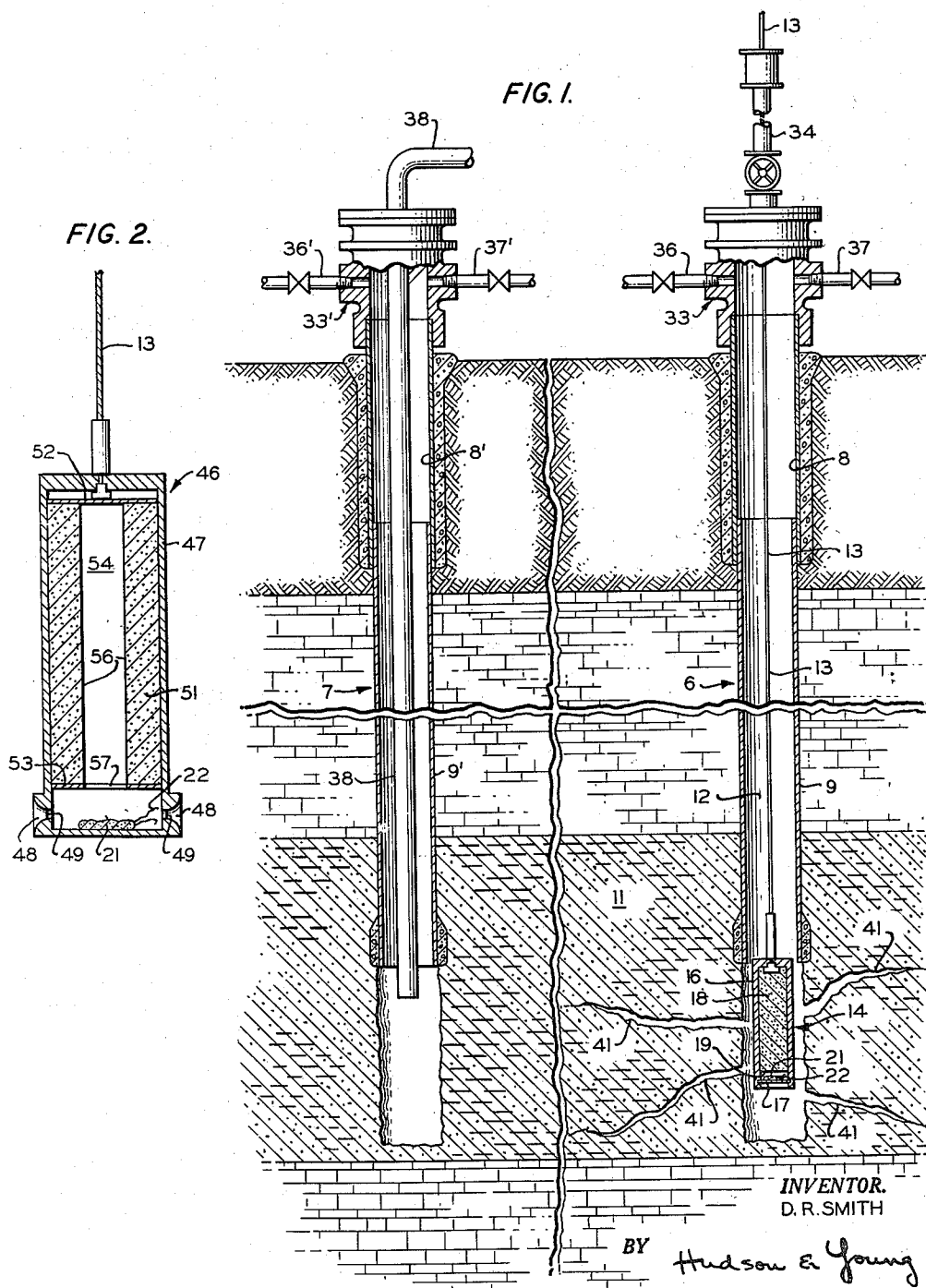
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METHOD AND APPARATUS FOR INITIATING SUBTERRANEAN COMBUSTION

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METHOD AND APPARATUS FOR INITIATING SUBTERRANEAN COMBUSTION

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8 Claims. (Cl. 166—11)

This invention relates to the recovery of hydrocarbons from subterranean reservoirs. In a more specific aspect it relates to a method and apparatus for initiating combustion of subterranean oil-bearing formations, and/or other carbonaceous formations in proximity therewith, so as to aid in the recovery of physically trapped hydrocarbon material and/or hydrocarbon material that is ordinarily too viscous to be produced by ordinary recovery methods.

The recovery of oil remaining in oil-bearing formations after depletion of initial reservoir energy has constituted a major challenge to the petroleum industry for a number of years. The oil may be initially produced by natural means such as gas or rock pressure, natural water drive, or solution gas pressure. When these natural forces are insufficient to cause the oil to flow from producing wells at an economical rate, the oil may be pumped or raised by any desired known method. When pumping methods are no longer effective in producing oil from a particular formation at an economical rate, additional oil may be recovered after depletion of the initial reservoir energy by conventional so-called secondary recovery methods, e.g., water flooding and gas repressuring. These secondary methods are mainly employed to effect higher recoveries of high gravity crude oil.

In the secondary recovery of oil from subsurface strata by methods known in the art, the ultimate recovery of oil has not been as great as desired. Such methods are often ineffective in increasing the ultimate recoveries of low-gravity and viscous crude oils. Of the various methods for increasing the recovery of the latter, those involving application of heat to the reservoir to increase mobility of the oil by decreasing its viscosity probably have received most attention. A conventional method, i.e., in-situ combustion, for recovering low-gravity and viscous crude oils comprises initiating combustion of a producing formation, and/or other carbonaceous formation in proximity therewith, and maintaining this combustion by supplying the burning formation with air or other oxidizing medium. A combustion zone or fire front is thereby established which continues to burn in the form of a slowly advancing high-temperature front of finite thickness as long as the necessary air or oxygen supply is maintained to support combustion. The supply of oxidizing medium may be pumped into the injection well behind the fire front or may be pumped into the producing well ahead of or countercurrent to the advancing fire front, such as by the "inverse air injection" method disclosed and claimed in the pending U.S. application, Serial No. 526,388, filed August 4, 1955, by J. W. Marx. According to whether the oxidizing medium is pumped behind or countercurrent to the advancing flame front, the resulting exhaust gases, including condensable hydrocarbon vapors, and fluid hydrocarbons are driven out of the formation into the bore hole in which burning was initiated or into the bore hole to which the oxidizing medium was supplied. Besides supporting combustion, the oxidizing medium is coupled with the viscosity reduction

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of the heated oil to drive the hydrocarbons from the formation.

Various means have been utilized in the past for initiating the combustion of the oil-bearing formation and/or other carbonaceous formation in proximity therewith and while some of these means perform satisfactorily, they either involve costly and complicated equipment or they cannot be desirably controlled or give uniform and quick combustion, and some of them deposit undesirable residues in the bottom of the bore hole. Electrical resistance-type heaters and gas burners have been employed and in addition to expense and complexity, care must be exercised to prevent explosions. Thermite bombs or other explosive charges are not as controllable as desired and, in the case of the former, a molten iron residue is deposited in the bore hole which often hinders subsequent operations.

An object of this invention is to provide an improved and novel method for initiating combustion of subterranean oil-bearing formations and/or other carbonaceous formations in proximity therewith.

Another object is to provide for the uniform and controlled initiation of combustion of subterranean petroleum reservoirs.

Another object is to provide a quick source of heat which can be utilized to initiate combustion of subterranean petroleum reservoirs.

A further object is to provide novel means for initiating combustion in a borehole adjacent a subterranean carbonaceous formation without depositing an undesirable residue thereon.

Other objects and advantages of this invention will become apparent to those skilled in the art from the accompanying specification, appended claims, and drawings in which:

Figure 1 is a broken sectional view illustrating diagrammatically installation and operation of this invention; and Figure 2 is a cross-sectional view of another embodiment of the novel igniter means shown in Figure 1.

Broadly contemplated, I propose to ignite subterranean oil-bearing formations and/or other carbonaceous formations in proximity therewith by novel means in order that the resulting heated fluid products of combustion and resulting pressure heat the oil remaining thereby lowering the viscosity of the oil so that it may subsequently be driven out from the formation. The means I propose to employ for initiating this combustion is a solid ignitable material or fuel the combustion of which, once initiated, is self-sustaining because it has its own oxidant so that it is unnecessary to supply air or oxygen to sustain combustion. The fuel may be placed inside of an expendable container and attached to a cable and lowered into a well to a point adjacent the subterranean formation desired to be ignited. Ignition of the fuel can be accomplished by any suitable ignition means such as an electrically actuated igniter or squib. The hot flame and combustion gases resulting from combustion of the fuel are preferably directed toward the formation to be ignited.

Referring to the drawings now, and to Figure 1 in particular, there is shown two wells generally designated 6 and 7. Well 6 comprises a surface casing 8 and a bottom hole casing 9, the latter being in communicating at its lower end with a carbonaceous layer or oil sand 11. Supported within the interior 12 of the casing by cable 13 is a burner generally designated 14, shown in elevational cross section, which comprises a container 16 closed at its open end by means of a blowout-type disk 17. Fuel 18 substantially fills the interior of container 16 and is restricted on its sides and upper end by the inside walls of container 16 to which it may be suitably bonded. Alternatively, these surfaces of the fuel may be bonded to suitable rubbery or plastic restricting material, not

shown, which may be in turn bonded to the walls of container 16.

In still another alternative, the outside layer of restricting material can serve as the exterior surface of the burner. The lower end 19 of the fuel is preferably the burning surface of the same and it is upon this surface that ignition of the fuel is initiated by means of a suitable primer 21 adjacent thereto which can be suitably supported on the inside of blowout disk 17. Igniter primer 21 can be any suitable means such as a cloth bag, plastic cup, or other container filled with black powder or the like. Suitable electric wires 22 can be placed in intimate contact with the primer igniter 21 and lead from the latter to suitable contacts of a power source exterior of well 6, preferably through cable 13 which can be an insulated conductor.

The upper end of cable 13 extends upwardly through a well head 33, surmounting the upper end of the surface casing 8, and lubricator 34. The cable 13 may be raised or lowered in the well 33 by any suitable means such as a power-driven cable drum, not shown. Well head 6 is provided with suitable conduits 36 and 37 either of which may be an inlet or outlet conduit for the egress of gaseous products of combustion or the ingress of air or other oxidizing medium.

Well 7, having its parts designated with primed reference characters which are otherwise the same as corresponding parts of well 6, is provided with producing conduit 38 which extends to that portion of the well bore in communication with the oil-bearing formation 11.

Referring to Figure 2, another embodiment of my novel burner generally designated 46 is shown, the lower portion of its container 47 being provided with a plurality of Venturi passages 48 for the exhaust of gases from the interior of the container 47. These passages 48 are provided across their throat with blowout-disks 49. The fuel 51 is restricted at both ends by suitable restricting plates 52 and 53 which in addition to restricting the burning surfaces of the fuel, aid in supporting the fuel 51 in the container 47. The outer wall of the fuel is bonded to the container 47 in the manner hereinbefore stated. The fuel 51 has an axial perforation 54 which is defined by the exposed or unrestricted burning surfaces 56 of the charge. The lower restricting plate 53 has an opening 57 in axial alignment with the perforation 54 and has a diameter that is substantially the same as or slightly smaller than that of the perforation 54. The igniter primer 21 such as shown in the igniter charge 14 of Figure 1, can be supported on the base portion of the container 47. Ignition of the igniter primer 21 causes the fuel 51 to ignite on the exposed surfaces 56 by reason of the propagation of the combustion gases from the former down the length of the perforation 54. The blowout-disks 49 are such that rupture of the same will only be effected by the generation of combustion gases from the fuel 51. The Venturi passages or nozzles 48 are so oriented that the passage of hot flame and combustion gases therethrough will be directed to the adjacent subterranean formation desired to be ignited.

In the preferred embodiment of this invention, the oil-bearing formation adjacent the burner is first artificially fractured by any conventional means, such as hydraulic fracturing, so as to form cracks or crevasses 41. For example, a heavy fluid such as gelled liquid hydrocarbon ("napalm") is injected into the formation around the bore hole with sufficient pressure to fracture the formation. The gelled liquid hydrocarbon in the resulting fractures can be then converted into a readily flowable liquid by the heat of formation or a gel-breaking agent or peptizer. Hydraulic fracturing also may be accomplished by using other suitable heavy liquids such as heavy crude and/or refined oil. A propping agent such as suspended sand can be used in conjunction with the fracturing fluid to hold the cracks open after release of pressure. Alternatively, the bottom of the bore hole may

be preliminarily enlarged by setting off explosive charges, such as nitroglycerine or the like, so as to form a conventional shot-hole.

After fracturing has been effected so that artificial cracks are created in the desired locale, a readily combustible material, such as napalm, gasoline, formaldehyde, etc., can be injected into the cracks adjacent the burner. Such an injection operation can be effected to insure ignition of the oil-bearing formation and/or other carbonaceous formation in proximity therewith. The readily combustible material injected into the artificial fractures is ignited by the burner upon ignition of its fuel. Alternatively, should sufficient carbonaceous material be present adjacent the bottom of the bore hole and be relatively readily ignitable, supplemental readily combustible material need not be injected into the artificial formation but, rather, ignition of the oil-bearing or carbonaceous formation can be effected directly upon ignition of the burner fuel adjacent thereto. However, in most formations I prefer to employ supplemental readily combustible material to insure a quick initial burning of the subterranean formation.

Where the bottom of the bore hole has been enlarged by explosive charges, the supplemental readily combustible material can be injected therein to insure the quick initial burning of the formation.

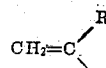
Where direct combustion of the oil-bearing formation is impractical or difficult, it is within the scope of this invention to ignite subterranean carbonaceous formations in proximity to the oil-bearing formation so as to allow the heat from the burning carbonaceous formation to heat the oil-bearing formation, such as disclosed in the U.S. Patent 2,584,605 to Edmund S. Merriam. For purposes of simplicity, I have designated in Figure 1 the reference character 11 as an oil-bearing formation such as oil sand or shale and it should be understood that 11 may designate a carbonaceous formation such as coal, ligneous material or other carbonaceous organic material which is in proximity to the oil-bearing formation to which heat from combustion of the former may be transmitted principally by conduction.

Basically, the fuel compositions employed in this invention comprise a rubbery or plastic binder and a solid oxidant. Representative rubbery binders useful in the practice of this invention include: GR-S; natural rubber; Butyl rubber; butadiene-methylvinylpyridine copolymer; butadiene-acrylonitrile copolymer; butadiene-methylvinylpyridine-acrylonitrile terpolymer; and various polysulfide polymers manufactured by Thiokol Corporation and designated LP-2, LP-3, LP-8, LP-32, and LP-34.

Representative plastic binders useful in the practice of this invention include: ethylcellulose; cellulose nitrate; nitrocellulose; cellulose acetate; methyl methacrylate; polyethylene; asphalt; pitch; tar; and the like.

Especially useful rubbery binders are copolymers of conjugated dienes and heterocyclic nitrogen base compounds such as disclosed in the pending U.S. application, Serial No. 284,447, filed April 27, 1952, by William B. Reynolds et al. In that application, the copolymers are produced by any suitable method, i.e., emulsion polymerization. The conjugated dienes employed therein are preferably conjugated diolefins which contain 4 to 6 inclusive carbon atoms per molecule, and representatively include: 1,3-butadiene; isoprene; piperylene; methylpentadiene, 2,3-dimethyl-1,3-butadiene; chloroprene; and the like.

The heterocyclic nitrogen bases, including the alkyl substituted bases, which are employed in preparing these copolymers are those which are copolymerizable with a conjugated diene and include the



substituted bases wherein R is a suitable substituent atom or group, e.g., a hydrogen atom or a hydrocarbyl group,

such as an alkyl group. The vinyl-substituted heterocyclic nitrogen bases of the pyridine and quinoline series having only one vinyl substituent group and their various alkyl-substituted derivatives thereof are preferred.

For the production of these copolymers the amount of conjugated diolefin employed is generally in the range of from 25 to 98 parts per 100 parts of the total monomeric material and the amount of copolymerizable heterocyclic base employed is in the range of from 75 to 2 parts per 100 parts of the total monomeric material, the proportion of the monomeric material employed depending upon the type of copolymer desired.

The following are typical formulations for the preparation of some rubbery binders useful in the fuel of this invention and it should be understood they are set forth for illustrative purposes and do not unduly limit my invention.

Table I.—Compositions of typical rubbery binders

Component (parts by weight)	Type of polymeric composition								
	LP-2	LP-3	LP-32	LP-33	Bd/MVP	GR-S	Natural rubber	Butyl rubber	Reclaim rubber
Polymer.....	100	100	100	100	100	100	100	100	100
TP-90 B ¹					20		20		
Carbon black.....	30		30		20		20	20	20
p-Quinone dioxime.....		7		7					
Diphenyl quatinide.....		3		3					0.2
C-5a ²	15		13.1						
Sulfur.....			0.1	0.1	0.75	2.0	3	2	3
Titanium dioxide.....		20		20					
Phileure 113 ³					1.0	1.0	1.0	1.0	1.0
Philplast ⁴						25	5	5	25
Zinc oxide.....							3	5	5
Benzophenone.....						20		20	20

¹ Di-(butoxy ethoxy ethoxy) methane.

² A physical mixture of 50 weight percent lead dioxide, 45 weight percent dibutyl phthalate, and 5 weight percent stearic acid.

³ N,N-dimethyl-5-tertiary butyl sulfenyl dithiocarbamate.

⁴ Rubber extender, a cut from clay tower residues.

These polymeric compositions can all be cured, for example, at 170° F. in 4 to 48 hours, and their preparation i.e., conditions of temperature, percentages, etc., are known in the rubber art.

The fuel compositions useful in this invention comprise a rubbery or plastic binder and an oxidant; in addition to these components, a burning rate catalyst can be incorporated where it is desired to control the burning rate of the fuel. Suitable burning rate catalysts which can be employed include ferrocyanides sold under various trade names such as Prussian blue, steel blue, bronze blue, Milori blue, Turnbull's blue, Chinese blue, new blue, Antwerp blue, mineral blue, Paris blue, Berlin blue, Erlanger blue, foxglove blue, Hamburg blue, laundry blue, washing blue, Williamson blue, and the like. Other useful burning rate catalysts include ammonium dichromate, potassium dichromate, sodium dichromate, ammonium molybdate, and the like.

Solid oxidants which can be used in preparing the fuel compositions of this invention include those oxygen-containing solids which are employed as oxidizing agents and/or which readily give up oxygen. Representatively these oxidants include ammonium nitrate and ammonium and alkali metal compounds, such as potassium and sodium perchlorate, chlorates, chlorites, and hypochlorites. Dichromates, chromates, chromites, and persulfates can also be employed. The oxidizers which are preferred in preparing the fuel used in this invention are potassium, ammonium, and sodium perchlorate. Although the ammonium, potassium, and sodium salts are preferred, salts of other metals such as lithium, especially the alkaline earth metals such as calcium, strontium, barium, and magnesium, as well as aluminum, boron, and the like, may be employed.

The following is a typical formulation for the preparation of fuels useful in the practice of this invention and is set forth for illustrative purposes.

Table II.—Fuel formulations

	Parts per 100 parts of rubber or plastic	Parts, weight percent
Binder.....		2-50
Rubber or plastic polymeric composition.....	100	
Plasticizer.....	0-30	
Cure agent.....	0-5	
Cure accelerator.....	0-3	
Fillers.....	0-30	
Oxidant.....		50-98

In general, the fuel compositions employed in this invention can be prepared by grinding or powdering the oxidant to a fine degree, e.g., 60-mesh or finer, and then incorporating or mixing it into the binder composition until a substantially uniform mixture is obtained. De-

pending upon the particular oxidant and binder employed, the temperature during the mixing can be controlled by cooling coils or the like. The compounded fuel mixture can then be extruded, molded, cast or the like and subsequently cured for an extended period of time. The restricting material can either be applied before curing or after curing and it can also be applied directly to the inner walls of the container with which the fuel comes into contact. The particular mode of preparation of the fuel compositions to be used will be apparent to those skilled in the art upon being acquainted with my invention.

The burning restricting material employed can be made of any slow-burning material such as cellulose acetate, ethylcellulose, butadiene-methyl-vinylpyridine copolymer, GR-S, and the like. Where a "cigarette-type" burning is desired, for example, the fuel can be molded or extruded in a cylinder and the outer surface and one end can be covered with the aforementioned restricting material so as to allow ignition of the fuel to be initiated on the exposed or unrestricted end, thereby allowing the burning of the fuel to proceed from the exposed to the restricted end similar to the burning of a cigarette. The amount of heat and combustion products evolved can be controlled to some extent by the method of restriction and that particular method which can be employed for optimum results will be apparent to those skilled in the art upon being acquainted with this invention. The amount of heat produced and the rate of burning of the fuel can also be controlled by the amounts of the various fuel ingredients and to some extent by a burning rate catalyst. The temperature resulting from the burning of the fuel must be above the auto-ignition temperature of the formation material desired to be ignited.

The restricted fuel can be bonded to the container by

any adhesive or other means. Alternatively, where the walls of the container itself are utilized to restrict the burning surface of the fuel, the latter can be bonded directly to the container walls by any of the commonly used adhesives.

The fuel can be placed inside of an expendable container and attached by suitable means to a cable containing electrical leads, or any other suitable means, to ignite the fuel. The burner is preferably of such configuration and is so disposed in the bore hole that ignition of the adjacent subterranean formation, or those fractures containing injected readily combustible material, such as napalm, will be readily ignited upon propagation of the flame and combustion gases of the burning fuel. The burning of the latter can be controlled by burning rate catalyst so as to produce a relatively long burning process and the initial ignition of the charge can be controlled by a mechanical or electrical timer or other suitable means. The container for the fuel can be made of any expendable material such as plastic, etc., which may also eventually burn or which will dissolve in the oil with which it comes into contact.

Upon ignition of the oil-bearing formation or other carbonaceous formation in proximity therewith, burning of the subterranean formation progresses radially outward from the well in which burning was initiated, as is well known to those skilled in the art. If advance of the flame front is arrested or if ceased, combustion can be re-established by lowering a second burner in the same or another well and re-igniting the formation by igniting the second burner.

As many variations and modifications will become apparent to those skilled in the art without departing from the scope of this invention, it should be understood that I do not intend to limit the same to the foregoing description and accompanying drawing.

I claim:

1. In a method for recovering hydrocarbons from a geological formation penetrated by at least one input well and at least one adjacent output well leading from the surface thereto which comprises burning said hydrocarbons so as to establish a fire front, and maintaining said burning with a combustion supporting gas whereby fluid hydrocarbons are driven to said output well and recovered therefrom, the improvement comprising introducing in said input well a body of solid fuel, the combustion of which is self-sustaining, in substantially the locale of said formation, igniting said fuel, and directing the hot flame and combustion gases resulting from the combustion of said fuel to said formation thereby initiating burning of same, said fuel comprising a minor amount of a combustible binder and a major amount of an inorganic oxidizing salt selected from the group of salts consisting of nitrates, chlorates, and perchlorates of ammonia, alkali metals, and alkaline earth metals.

2. In a method for recovering of hydrocarbons from an underground oil-bearing formation penetrated by at least one input well and at least one adjacent output well leading from the surface thereto which comprises burning said hydrocarbons in a restricted area of said formation so as to establish a fire front, maintaining said burning by supplying said formation with a combustion supporting gas whereby fluid hydrocarbons are driven from said formation to said output well and recovered therefrom, the improvement comprising lowering in said input well down to the general locale of said formation a body of solid fuel comprising a major amount of ammonium perchlorate as an oxidant and a minor amount of a combustible rubbery material as a binder, igniting said fuel electrically, and directing the hot flame and combustion gases resulting from the combustion of said fuel toward said formation thereby initiating combustion of same.

3. In a method for the recovery of hydrocarbons from a partially depleted underground oil-bearing formation penetrated by at least one input well and at least one adjacent output well which comprises artificially fracturing said formation to provide passages from said input well to said output well, injecting a combustible material in said passages in substantially the locale of said input well, burning said hydrocarbons in a restricted area of said formation so as to establish a fire front, maintaining said burning by supplying said formation with a combustion supporting gas so as to heat said formation and render the hydrocarbons therein more fluid, and driving said fluid hydrocarbon from said formation to the locale of said output well and recovering the same therefrom, the improvement comprising lowering in said input well down to the general locale of said formation a body of solid fuel comprising a major amount of ammonium nitrate as an oxidant and a minor amount of a combustible rubbery material as a binder, igniting said fuel electrically, and directing the hot flame and combustion gases resulting from the combustion of said fuel toward said passages to initiate the burning of said combustible material whereby the burning of said hydrocarbons is initiated in turn.

4. In a method for the recovery of hydrocarbons from oil-containing deposits located in geological formations interstratified with other combustible organic matter penetrated by at least one input well and at least one adjacent output well, which comprises burning said organic matter and thereby heating by conduction the adjacent oil to cause the same to vaporize and fluidize, and recovering the same from said output well, the improvement comprising lowering in said input well down to the general locale of said organic matter a body of solid fuel comprising a major amount of an oxidizer and a minor amount of a combustible rubbery polymer as a binder, said oxidizer being a salt selected from the group of salts consisting of nitrates, chlorates, and perchlorates of ammonia, alkali metals, and alkaline earth metals, igniting said solid fuel electrically, and directing the hot flame and combustion gases resulting from the combustion of said fuel toward said organic matter thereby initiating combustion of same.

5. A method of treating a well, comprising lowering into said well to a predetermined depth a container containing a body of solid fuel the combustion of which is self-sustaining, and igniting said solid fuel, said solid fuel comprising a minor amount of a combustible binder and a major amount of an inorganic oxidizing salt selected from the group of salts consisting of nitrates, chlorates, and perchlorates of ammonia, alkali metals, and alkaline earth metals.

6. The method according to claim 5 wherein said inorganic oxidizing salt is ammonium nitrate and said binder comprises a rubbery polymer.

7. The method according to claim 5 wherein said inorganic oxidizing salt is ammonium perchlorate and said binder comprises a rubbery polymer.

8. A method of treating a well comprising lowering into said well to a predetermined depth a container containing a body of solid fuel the combustion of which is self-sustaining, and igniting said solid fuel, said solid fuel comprising 2 to 50 parts by weight of a combustible rubbery copolymer of butadiene and methylvinylpyridine and 50-98 parts by weight of ammonium nitrate.

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