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R. P. DIXON

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USE OF NUCLEAR DETONATIONS IN PRODUCING HYDROCARBONS
FROM AN UNDERGROUND FORMATION
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FIG. 1

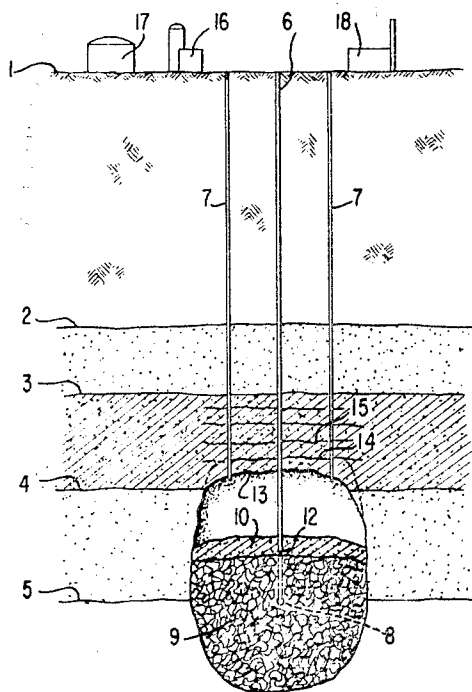


FIG. 2

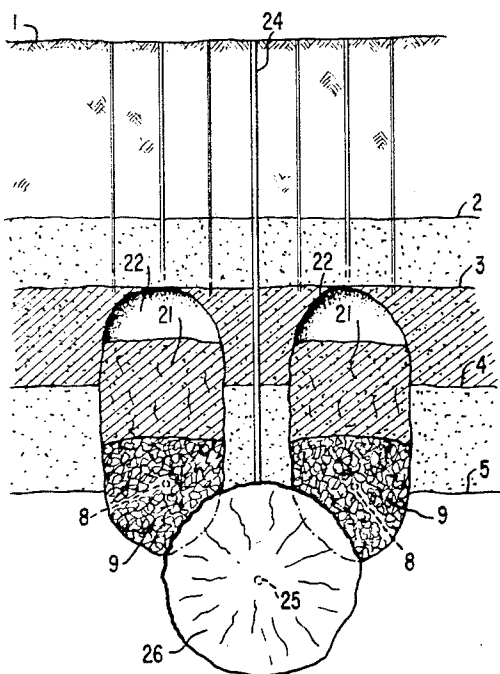
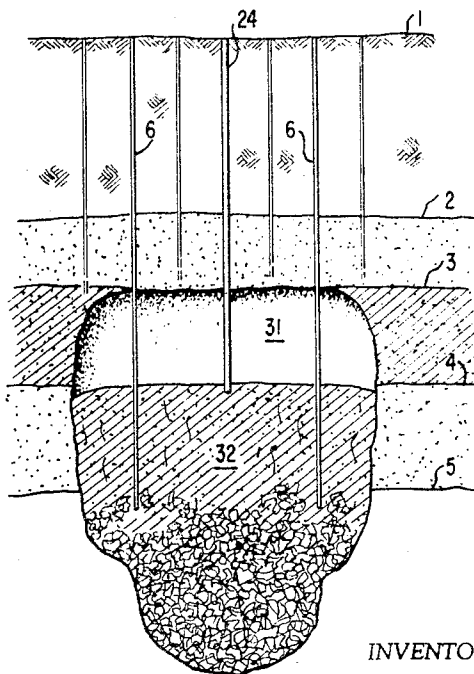


FIG. 3



INVENTOR

ROD P. DIXON

BY Burns, Doane, Benedict, Swicker & Mathis

ATTORNEYS

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USE OF NUCLEAR DETONATIONS IN PRODUCING HYDROCARBONS FROM AN UNDERGROUND FORMATION

Rod P. Dixon, Salt Lake City, Utah, assignor to American Oil Shale Corporation, Salt Lake City, Utah, a corporation of Utah

Continuation-in-part of application Ser. No. 547,672, May 4, 1966. This application Feb. 13, 1967, Ser. No. 615,444

Int. Cl. E21b 43/26, 43/24

U.S. Cl. 166—247

10 Claims

ABSTRACT OF THE DISCLOSURE

Nuclearly detonated formations are generally very extensive in scope and therefore it is difficult to drive hydrocarbons therefrom without channeling. When underground retorting of the nuclear rubble is resorted to in order to improve product recovery, residual heat is wastefully left behind. The present invention limits and controls the extent of caving of the hydrocarbon bearing stratum and thereby avoids or substantially reduces the problem of channeling. In another aspect, the present invention maximized the utilization of the thermal energy released in retorting by caving portions of untreated hydrocarbon bearing stratum onto the hot ash left from a previous retorting step and using the heat in the ash to distill hydrocarbons from the as yet untreated portions.

Cross reference to related applications

This application is a continuation-in-part of application Ser. No. 547,672, filed May 4, 1966, now U.S. Patent 3,404,919, which in turn is a continuation-in-part of Ser. No. 325,721, filed Nov. 22, 1963, now U.S. Patent 3,303,881. The latter in turn is a continuation-in-part of applications Ser. No. 789,747, filed Jan. 6, 1959 and Ser. No. 833,443, filed Aug. 13, 1959, both now abandoned.

Background of invention

Much study has gone in recent years into the problem of using nuclear energy for mining various minerals and particularly oil shale. However, the development of an effective process of this kind has progressively brought to light a number of difficulties requiring solution. For instance, in recovering fluid hydrocarbons from a permeable formation with the aid of a positive drive such as a gas drive or a water drive, it has long been recognized that such a drive is quite inefficient unless the formation is relatively limited as to vertical extent. Otherwise, the driving fluid tends to channel preferentially through major fissures while leaving other portions of the formation untreated.

Since in using nuclear devices in fragmenting a geological formation it is generally desirable for reasons of economy to use the largest device which can be safely detonated at a given depth without venting to the atmosphere, it has heretofore been proposed to mine oil shale with the aid of very powerful nuclear devices which create a very extensive fragmentation by a single detonation. For instance, the detonation of a 50 kiloton device in an oil shale stratum will in a typical case create a chimney of fragmented oil shale about 260 feet in diameter and 650 feet high. If the fragmented oil shale in such a chimney is restored in situ in a mater such as that proposed in U.S. Patent 3,113,620 to Hemminger, excessive channeling will make such retorting very inefficient in that a large part of the shale rubble will be by-passed by the hot combustion gases which are sup-

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posed to convert the kerogen of the shale into fluid hydrocarbons by destructive distillation.

Inefficiency in such an in situ retorting operation is also attributable to the fact that a large amount of potentially useful heat remains underground in the hot ash upon completion of the retorting operation and is gradually dissipated without producing any useful effect.

It is among the objects of this invention to provide a process based on the use of nuclear detonations in mining minerals wherein the fragmentation of the geological formation is controlled in such a way that subsequent channeling of treating fluid therethrough is kept at a minimum. Another object of the invention is to increase the utilization of the thermal energy released in situ retorting of a nuclearly fragmented formation.

These and other objects, as well as the nature, operation and scope of this invention will become apparent from the following description and appended claims.

Summary of invention

The present invention provides an improved process for using nuclear explosive devices in the production of fluid products from a productive stratum such as oil shale in a manner such that good use is made of the great power of nuclear devices in creating permeability in the stratum while keeping subsequent channeling of treating fluid in the stratum within acceptable limits.

More particularly, in the present invention a nuclear device of large size is detonated below the floor or bottom boundary of the productive stratum to be treated such that a large cavity is created near the bottom of the stratum and only a limited amount of fragmented shale is caved into it forming a chimney of permeable rubble of which only a layer of limited depth, such as 10 to 50 feet, comprises shale to be treated. This layer can then be retorted in situ by blowing a combustion supporting gas such as air into the fragmented or rubblized stratum, initiating combustion, and withdrawing the resulting flowable oil through a well bore extending into the area being retorted. For instance, air may be blown into the chimney substantially at the center of the fragmented shale rock and vapor and/or liquid product may be withdrawn near the periphery of the chimney of fragmented shale rock, as the combustion gases drive the desired product ahead of them.

When the initial fragmented layer has been retorted and burnt out, a new limited layer of fragmented shale is dropped down on the burnt out layer by forcing additional explosive, which may be conventional liquid nitroglycerin or TNT, into the horizontal fractures in a limited depth above the cavity through a plurality of wells, such as the wells used for product recovery in the previous stage of the process, and detonating the explosive. This collapses the frail ash left behind from the retorting of the first fragmented layer and forms an essentially impermeable floor under the newly dropped rubble. Thereafter, retorting of the second rubblized layer and recovery of product therefrom is undertaken similarly as before, and the sequence of dropping new rubblized shale layers of therefrom can be repeated until the full depth of the shale stratum has been exploited. In this manner separate layers of rubblized shale of limited depth are formed and treated in sequence, such that each layer is bounded at the bottom either by essentially incombustible country rock in the first cycle or by a floor of compacted shale ash in subsequent cycles and bounded at the top by a cavity and an essentially impermeable roof. Because of this configuration, channeling is avoided or kept to a minimum.

In another aspect, the invention makes it possible to make use of the thermal energy contained in the hot ash subsequent to retorting of a given area or vertical chim-

ney in treating an adjacent area. More particularly, after one chimney, or a plurality of chimneys laterally separated from each other by untreated formation, has been fully retorted and product recovered therefrom, a large thermonuclear device is emplaced under the untreated formation adjacent the treated chimney or chimneys such that upon detonation of this device the hot ash from the previously treated areas will cave laterally downward into the cavity formed by this last described nuclear detonation and the shale above this last described nuclear detonation will become fragmented into permeable rubble and drop on top of or become mixed with the previously formed hot ash. The heat contained in this ash then will serve to distill product from the newly fragmented shale. If desired, after completion of this distillation step additional product can be recovered from this formation by retorting.

Further description

The underground use of thermonuclear devices in fragmenting or fracturing various carbonaceous or hydrocarbon bearing formations to create the permeability necessary for the recovery of fluid product therefrom has been broadly described in my earlier copending applications Ser. No. 325,721 filed Nov. 22, 1963, now U.S. Patent 3,303,881, Ser. No. 541,810 filed Apr. 11, 1966 and Ser. No. 547,672 filed May 4, 1966, now U.S. Patent 3,404,919, and the disclosures of those applications are incorporated herein by reference to avoid wasteful repetition.

Suffice it to say that in those earlier applications it was pointed out that the use of thermonuclear devices is applicable to the treatment of a wide variety of formations, ranging from insufficiently permeable formations holding natural gas locked therein to oil shale and other bituminous formations containing solid or viscous liquid hydrocarbons which are incapable in their natural state to flow through the formation and be recovered through a producing well. The nature and practical sizes of thermonuclear devices useful in such operations have also been described previously as have the criteria determining the required depth of placement for a given size of device to prevent the venting of radioactive debris to the atmosphere. It is also well known by now and may be only briefly restated that upon detonation of a thermonuclear device underground the formation near the center of the detonation is vaporized and forms an essentially spherical cavity, the areas next to the vaporized portion are melted and eventually run down along the walls of the cavity forming an impermeable floor at the bottom, beyond the melted areas are areas of finely crushed mineral the extent of which depends on the nature of the formation, and beyond the crushed zone there are fractures radiating more or less laterally outwards from the center of detonation. Then, after the cavity has become fully expanded it begins to contract and in most formations, including oil shale, the roof of the cavity caves in and thus partially fills the cavity with a mass of fractured, permeable rubble. This permeable mass of rubble is then essentially in the form of a vertical cylinder or chimney several hundred feet in diameter and several hundred feet tall from which fluid product, released by the heat of the thermonuclear detonation, can be recovered through suitably placed recovery wells of essentially conventional design.

Of course, the extent of the roof failure or cave-in again depends to some degree on the nature of the formation, the tendency to roof failure being greatest in jointed formations such as shale, intermediate in bedded formations such as sedimented rock salt, and smallest in homogeneous salt formations. As I have also previously described, by detonating a plurality of nuclear devices in a predetermined spaced relationship the total net effect can be modified in terms of more effective utilization of the available thermal and fragmentation energy available as well as in terms of creating permeability throughout a larger portion of the formation to be treated than if mul-

multiple detonations are set off without any functional correlation.

When reliance on nuclear detonations alone does not result in a sufficiently high degree of product recovery from formations such as oil shale, the subsequent reliance on secondary recovery treatment by retorting or the like may be advantageous. However, in view of the vast scope of the nuclearly created chimney containing the rubble being treated, and because unlike in conventional retorting of oil shale the degree of control over the particle size of the nuclearly created rubble to be retorted underground is quite limited, channeling will cause the secondary recovery treatment to be inefficient and, in the case of retorting, will let a large amount of thermal energy go to waste underground upon conclusion of the retorting operation. These are the problems to which the present invention addresses itself as will be described in detail hereafter.

Generally speaking, it is also recognized that the larger the size of a thermonuclear device, the more economical is the energy obtainable therefrom. However, in using such large devices in underground detonations, the less accurately predictable is the extent of eventual fracturing and caving produced thereby. Consequently, it is increasingly believed necessary to allow considerable margin of safety in emplacing large thermonuclear devices at a depth which will not only assure against the venting of radioactivity into the atmosphere, but also prevent fractures from extending upward into aquifers or water bearing strata which overlie the strata to be treated.

For instance, improperly executed nuclear detonations in oil shale fields in Colorado could cause radioactive contamination of water in the area which could eventually affect the supply of potable water as far away as Los Angeles. Also, fracturing unintentionally extending into an aquifer could drain off large amounts of water into a nuclearly detonated chimney and thus seriously diminish the supply of this increasingly critical resource. This is another problem which the present invention serves to solve.

Description of the drawings

FIG. 1 is a section through a mineral formation containing a shale stratum which has been treated by a combination of nuclear and conventional explosions and a series of retorting steps.

FIG. 2 is a section through the same formation containing a pair of treated zones of the type shown in FIG. 1, between which a further nuclear detonation has been set off and a cavity created so as to produce permeability between the two previously treated zones; and

FIG. 3 is a section through the same formation after collapse of the cavity shown in FIG. 2 and essentially in operating condition.

Exemplary embodiment

An exemplary embodiment of the invention will now be described with reference to the attached drawing. In this embodiment the invention is applied to a shale deposit such as the one located in Rio Blanco County, Col., e.g., Section 24, Township 1 S., Range 98 W. The stratum of pay shale to be treated here is about 1700 feet thick with about 1200 feet of lean shale and country rock as overburden on top of it. Of course, more lean shale and country rock are beneath it.

In the drawing the earth surface is designated by numeral 1, the beginning of the lean shale is shown at 2, the approximate boundary between the lean shale and the top of the pay shale is shown at 3, the approximate bottom of the pay shale is shown at 4, and the bottom of the lean shale is shown at 5. The pay shale stratum to be treated has an average kerogen content which if fully recovered yields about 25 gallons of oil per ton.

Safe depth of underground placement of a nuclear device or bomb can be calculated from the equation

$$D=450W^{1/3}$$

wherein D is the depth of placement in feet and W is the potential energy yield of the nuclear device in kilotons. Accordingly, a 50 kt. device can be safely contained at a depth of about 815 feet. In the present case, a 50 kt. device shown at 8 is placed in the formation through well 6 at a depth of about 3525 feet. After detonation and collapse of the roof of the initial nuclearly created cavity, this device creates above the shot point a chimney approximately 650 feet high having a roof 13. The detonation thus bites through the country rock and lean shale and only partially, to the limited extent of about 25 feet, into the pay shale stratum to be treated. It is estimated that the chimney will have a diameter of about 265 feet and contain about 35 million tons of rubble. The bulk of this, as shown at 9, is fragmented country rock and lead shale, and only the top portion 10, amounting to about 1.2 to 1.5 million tons, will be fragmented pay shale. Exact location of ultimate roof failure cannot be accurately predicted, but can be accurately determined after the shot by drilling a well into the cavity. If it is then found that insufficient pay shale was caved down by the nuclear detonation, additional caving may be produced to the extent desired by forcing liquid TNT into the fractures in the shale formation at an appropriate level, e.g., at a depth of 1875 feet below the earth surface, and thus block caving an additional amount of pay shale into the top of the cavity to raise its roof to level 13 as desired. Flowable hydrocarbons distilled from the shale rubble by the heat of the thermonuclear explosion is then recovered through one or more recovery wells 7 drilled into the roof of the chimney near its periphery.

When this hydrocarbon production ceases, well 6 which was plugged prior to the nuclear detonation is re-drilled through cavity roof 13. A limited amount of an easily ignitable fuel such as gasoline is then injected into the rubble through well 6, ignited by an electrical spark or by other conventional means, and air or other combustion supporting gas is blown in above the fragmented shale to sustain combustion therein. As the underground retorting of the fragmented shale progresses downwardly through the fragmented shale the hot combustion gases cause distillation of the residual kerogen and drive out the resulting hydrocarbon bases and condensable vapors which are drawn off through recovery wells 7 which for this operation are extended to the bottom of the fragmented shale zone. In view of the limited depth of zone 10 channeling in it will be kept at a minimum.

When retorting of zone 10 is substantially complete, conventional explosive such as nitroglycerine or TNT in liquid form is forced into fractures of the formation at level 14 and detonated to cave another layer of fragmented shale, about 10 to 50 feet, down onto the hot ash remaining after the previously described retorting operation. As this rubble falls down onto the ash its weight compresses the ash and forms a new impermeable floor under the freshly fragmented shale. At this stage another retorting cycle is started as described before, recovering additional product from this batch of fragmented shale, and when this retorting is complete, a further batch of shale is caved down by injecting conventional explosive at level 15 and detonating it. This sequence of fragmenting limited amounts of shale and retorting them underground is repeated until the entire shale zone has been treated.

The oil product taken above ground can be converted and separated in plant 16 into commercially valuable products which are finally stored in one or more storage tanks 17, and into a low grade heavy residue which can be burnt in a steam generating plant 18 whence the resulting steam can be injected back into the formation to promote product recovery.

Referring to FIGURE 2, another modification of the invention is illustrated whereby total energy utilization is importantly increased. In this embodiment, a plurality of laterally spaced chimneys is formed by a combination of explosions of nuclear devices placed as shown at 8 and

retorting of the fragmented shale above the points of explosion. Referring to FIGURE 2, there is shown the rubblized country rock at 9 at the bottom with a layer of hot shale ash 21 above it generally corresponding to the sequence of retorted shale layers 10, 14 and 15 previously described in connection with FIGURE 1. The numeral 22 shows the cavity at the top of such a chimney in a shale zone after it has been fully retorted. The ash after completion of the retorting is at a high temperature, e.g., between about 800° and 1200° F.

At this stage an access well 24 is drilled to point 25 at a depth substantially below the original placement of devices 8, e.g., to 3500 feet. A large thermonuclear device, e.g., a 100 kt. unit is then emplaced at 25 and detonated creating a cavity 26 and thereby, after roof failure, creating permeability between the previously described zones of hot retorted ash.

FIGURE 3 shows a cavity 31 atop the mass 32 of fragmented country rock and particularly shale after the roof failure of cavity 26 shown in FIGURE 2. The explosion which created the cavity 26 by vaporization of country rock creates upon full expansion temperatures in the range of 3000° C. and basically functions in the same manner as the explosions described previously and causes downward collapse of the fragmented shale formation above it as well as a downward slide of the hot ash remaining in the previously retorted zones 21. The resulting permeability and intermixing of hot ash and fragmented oil shale will permit circulation of hot gases and vapors or liquids throughout the entire mass causing within a period of about 60 to 90 days' substantial equalization of temperature within the rubblized zone.

To the extent that cavity 26 overlaps the hardened, previously melted rock resting at the bottom of the previously described nuclear chimney containing the retorted ash residue, this hard rock will be re-melted and run to the bottom of new cavity 26 and the released radioactivity thereof will be entrapped in this melted material.

As the cavity roof progressively collapses and broken rock falls into the cavity the hot compressed gases such as carbon dioxide and hydrogen collected in the cavity travel upward throughout the new permeable formation and distribute therein the heat of the cavity and by fluxing and refluxing distribute into the fragmented shale mass the 1500° F. heat of the melted rock and the 1000°–1200° F. heat of the hot ash. In this manner the average temperature of the entire mass 32 will be between about 500°–800° F. As condensable shale oil distills out of this heated mass it will travel upwardly into cavity 31 and is there taken to the surface through wells 6 and 24.

When production has fallen below a desired rate, well 24 is driven to the bottom of the rubblized zone. High energy steam may be inserted through well 24 which steam will circulate through the rubblized mass moving upwardly, distilling out additional hydrocarbons which are recovered through well 6.

It should be understood that while the invention has been described and illustrated principally in connection with the treatment of oil shale formations, it is similarly applicable to other formations which contain hydrocarbons that do not naturally flow in the formation at an adequate rate to permit good primary recovery and that therefore require an after-treatment by in situ retorting or the like for secondary recovery. Such formations accordingly may be tar sands, oil sands, bituminous limestone, kerogen rocks, peat coals, anthracite coals, as well as petroleum crudes requiring improved fluidity.

It should likewise be understood that while the invention has been described and illustrated principally in terms of using nuclear explosives having an explosive force equivalent to between about 40 and 100 kilotons of TNT, smaller or larger nuclear explosives can be used similarly provided that their emplacement in the formation is suitably chosen so as to avoid venting to the atmosphere while causing fracturing in the preselected strata.

I claim:

1. In a process for producing fluid hydrocarbons in a formation containing a pay stratum which is rich in hydrocarbonaceous mineral material that is not naturally flowable, said stratum being on top of a lower stratum of mineral wherein the hydrocarbon content, if any, is substantially less than in said pay stratum, the improvement which comprises:

emplacing at least one detonable nuclear energy device in said formation in said lower stratum at a depth substantially below said pay stratum and sufficient to contain the detonation of said device without venting to the atmosphere and such that upon detonation a chimney of rubble capped by a cavity is formed, said chimney extending from the place of detonation upward through said lower stratum and only partially and to a substantially predetermined limited extent into said pay stratum and consequently having a lower portion of rubble composed essentially of mineral from said lower stratum and an upper portion of rubble of substantially predetermined limited depth composed essentially of said hydrocarbonaceous mineral material, whereby fragmentation of said pay stratum is controlled in such a way that subsequent channeling of treating fluid therethrough is kept at a minimum,

detonating said device,

injecting a combustion supporting gas into said rubble in at least one location,

inducing burning and retorting the hydrocarbonaceous portion of the rubble to release fluid hydrocarbons therefrom,

withdrawing the released hydrocarbons from the retorted rubble at a location spaced from the point of injection of the combustion supporting gas and leaving behind a hot mineral residue,

and then dropping down on the hot mineral residue another limited layer of fragmented pay stratum for further retorting and recovery of hydrocarbons therefrom.

2. A process according to claim 1 wherein the hydrocarbonaceous material is oil shale.

3. A process according to claim 1 wherein the hydrocarbonaceous material is bituminous sandstone.

4. A process according to claim 1 wherein said detonable nuclear energy device is placed in said formation at a depth such that after detonation thereof the portion of rubble in said chimney composed essentially of hydrocarbon bearing material is between about 10 and about 50 feet thick.

5. A process according to claim 1 wherein after recovery of hydrocarbons from said nuclearly detonated portion of rubble of predetermined limited depth the next limited layer of fragmented pay stratum is dropped down by detonation of a conventional explosive, and after retorting of the last mentioned limited layer and recovery of hydrocarbon therefrom further limited layers of pay stratum are dropped down and retorted for recovery of hydrocarbons therefrom until substantially the full depth of the pay stratum has been exploited.

6. In a process for producing fluid hydrocarbons by nuclear detonation in a mineral formation containing a stratum having an upper and a lower boundary between which solid or excessively viscous hydrocarbonaceous material is present,

the improvement which comprises emplacing a first detonable nuclear energy device in said formation below the upper boundary of said hydrocarbonaceous stratum at a depth sufficient to contain the detonation without venting to the atmosphere,

detonating said device and thereby forming a first chimney of rubble which comprises said hydrocarbonaceous material,

injecting a combustion supporting gas into said rubble, inducing combustion and retorting the hydrocarbon-

aceous rubble whereby fluid hydrocarbons are released therefrom leaving behind in said first chimney a hot mineral residue,

withdrawing the released hydrocarbons from the hot retorted rubble at a location spaced from the point of injection of the combustion supporting gas,

emplacing a second detonable nuclear energy device in the formation at a depth sufficient to contain its detonation without venting to the atmosphere, deeper than said first device and at a distance from the point of detonation of said first device such that said heated mineral residue and adjacent unretorted hydrocarbonaceous material upon detonation of said second device will cave into the cavity resulting from the last mentioned detonation,

detonating said second device and thereby forming a second chimney containing said heated mineral residue and rubble formed from said adjacent hydrocarbonaceous material, whereby the hydrocarbonaceous rubble in said second chimney becomes heated by the heat of the mineral residue as well as by the heat released in the detonation of said second device and fluid hydrocarbons are released from the said rubble,

and recovering the released fluid hydrocarbons from said second chimney.

7. A process according to claim 6 wherein the recovered fluid hydrocarbons are fractionated to separate them into desired products and an unwanted combustible residue, burning said combustible residue, using the heat liberated in this combustion to form steam, and injecting the resulting steam into a lower portion of said second chimney to further heat the released fluid hydrocarbons and facilitate their flow.

8. A process according to claim 6 wherein said second device is substantially larger than said first device, and is emplaced at a location laterally spaced therefrom.

9. A process according to claim 6 wherein a plurality of nuclear devices of substantially equal size are emplaced at substantially the same depth, sufficient to contain the detonations of said devices without venting to the atmosphere, and at a lateral spacing from each other such that their respective chimneys of hydrocarbonaceous rubble remain separated from each other by substantially unfragmented hydrocarbonaceous material,

each of said plurality of nuclear devices is detonated and the hydrocarbonaceous material in the resulting chimneys is retorted producing fluid hydrocarbons which are recovered and a hot ash which remains behind,

and thereafter a further nuclear device of a larger size is emplaced approximately at the midpoint between the aforesaid chimneys at a depth sufficient to contain the detonations of said devices without venting to the atmosphere and greater than the aforesaid plurality of devices were emplaced, the size of said larger device being such as to form upon detonation a relatively large chimney containing the ash from the previously recited retorting operation and further containing newly fragmented rubble resulting from the fragmentation of the previously unfragmented hydrocarbonaceous material which separated the chimneys resulting from the detonation of the first recited plurality of nuclear devices,

detonating said larger nuclear device and thereby forming said relatively large chimney wherein said newly fragmented rubble becomes heated by the heat contained in said hot ash,

and recovering fluid hydrocarbons from said relatively large chimney.

10. A process according to claim 6 wherein said first and second detonable devices are placed in the formation at such depths that after detonation of each of said devices a layer of broken rubble composed essentially of

hydrocarbon bearing material between about 10 and about 50 feet thick is formed.

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STEPHEN J. NOVOSAD, Primary Examiner

U.S. Cl. X.R.