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[54] METHOD OF PRODUCING PARTICLES OF ROCK
IN A SUBTERRANEAN SITUS
4 Claims, 5 Drawing Figs.

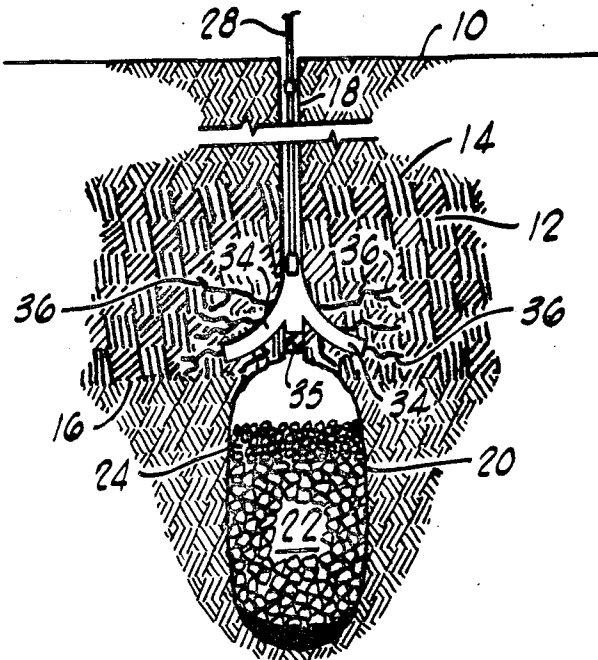
[52] U.S. Cl..... 166/299,
166/247, 166/308

[51] Int. Cl..... E21b 43/26

[50] Field of Search..... 166/247,
299, 308; 102/21, 21.6

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ABSTRACT: The method of producing an accumulation of broken rock in a subterranean situs which includes the steps of forming a system of fractures of predetermined minimum width in the earth above a cavity and selectively emplacing an explosive in the fractures. The selectivity of the explosive emplacement is with respect to the vertical width of the fractures in which the explosive is placed, and is achieved by control of the mobility of the explosive, primarily, but not necessarily exclusively, through control of the explosive viscosity. After emplacement of the explosive in selected horizontally extending fractures of a critical minimum vertical thickness, the explosive is detonated to spall fractured rock into the subjacent cavity.



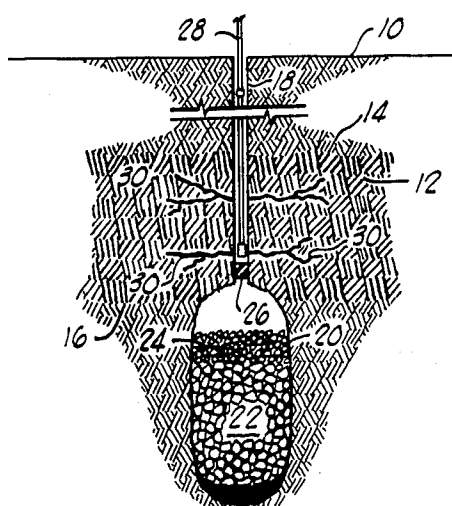


FIG. 1

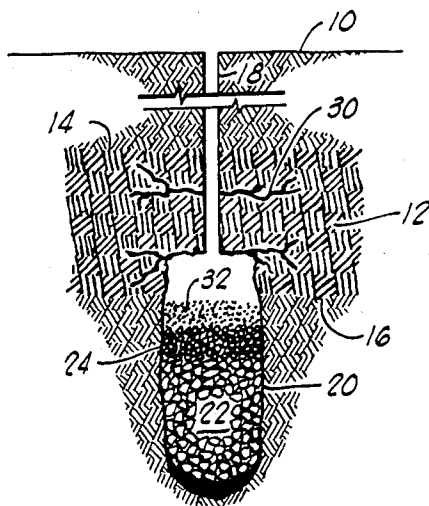


FIG. 2

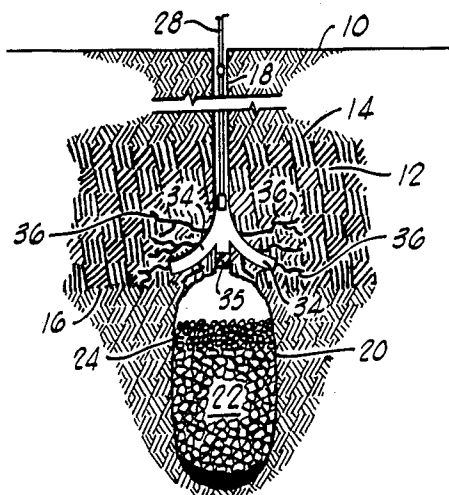


FIG. 3

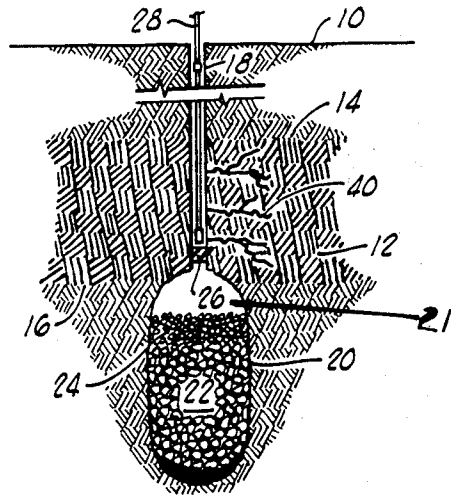


FIG. 5

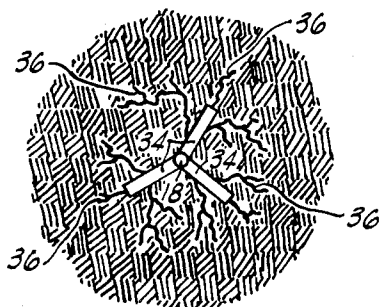


FIG. 4

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METHOD OF PRODUCING PARTICLES OF ROCK IN A SUBTERRANEAN SITUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to the mining of subterranean mineral deposits, and more specifically, but not in a limiting sense, to the nuclear mining of hydrocarbon deposits by caving selected portions of an overlying rock formation into a large underground cavity by emplacing and detonating a flowable (i.e., liquid, plastic, or slurried) explosive material in fractures contained in the rock formation.

2. Brief Description of the Prior Art

Much study has recently been devoted to the use of explosive energy for recovering various products from underground mineral formations. In one technique which has been proposed, a high-energy explosive device is detonated near the floor or bottom boundary of an underground productive stratum, creating a large cavity which collapses to form a chimney containing permeable rubble, which has a layer of the productive stratum near the top thereof. This layer may be treated in situ by leaching or heating to recover the desired products therefrom. When the initial layer of fragmented productive stratum has been treated, a new layer is caved into the chimney and treated. This process is repeated until the full depth of the productive stratum has been caved into the chimney and treated.

In Dixon U.S. Pat. No. 3,465,818, the use of conventional explosive material has been proposed in very general terms for selectively caving portions of overlying rock formations into large cavities for subsequent in situ treatment. Critical parameters relating to the proper placement of the explosive material to obtain adequate and efficient fragmentation and caving, however, is not recognized and has not been economically optimized.

SUMMARY OF THE PRESENT INVENTION

The present invention relates to a method of caving layers of an overlying rock formation into an underground cavity comprising the steps of emplacing liquid explosive material in fractures positioned above the roof of the cavity and of sufficient vertical width to allow effective detonation of the explosive; then detonating the liquid explosive material, thereby causing a layer of said overlying rock formation to be fragmented and to fall into said cavity. The selective emplacement of the explosive in fractures of the type described is achieved by controlling the fracturing pressure to produce fractures of at least the minimum width while at the same time controlling the mobility of the explosive, either through regulation of its viscosity, or by limiting the accessibility of cracks and fractures to the explosive.

It is, therefore, a general object of the present invention to provide a method of caving overlying rock into an underground cavity.

A further object of the present invention is the provision of a method of spalling selected layers of an overlying rock formation into an underground cavity by using a liquefied explosive material.

Yet a further object of the present invention is the provision of a method of caving selected layers of overlying rock formation into an underground cavity so that maximum caving and fragmentation of the rock formation is effected with a minimum quantity of explosive material.

Other and further objects of the present invention will be evident from the following detailed description of the invention when such description is considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a section through subterranean strata having formed therein an explosive produced chimney, showing fractures developed above this chimney in accordance with one technique of the present invention.

FIG. 2 is a sectional view similar to that appearing in FIG. 1, showing the formations after a selected portion of the overlying rock has been spalled into the apical cavity.

FIG. 3 is a section through a formation of the same type as shown in FIGS. 1 and 2 which has been fractured in accordance with another technique of the present invention.

FIG. 4 is a top view of the section of the formation shown in FIG. 3.

FIG. 5 is a sectional view similar to that shown in FIGS. 1-3 showing an asymmetric fracture pattern utilized to increase the effectiveness of explosive material within the fractures.

DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

Referring to the drawings, the earth's surface is designated by the numeral 10, and is underlain by a formation containing economic minerals such as oil shale, designated by numeral 12, having a top boundary 14 and a bottom boundary 16. A well 18 extends from the surface 10 to a chimney 20 of the type formed by detonation of a large explosive. A major portion of the chimney 20 is filled with fragmented country rock and lean shale 22 from below the oil shale formation 12, leaving an apical void 21. A layer 24 of fragmented oil shale makes up the top layer of the rubble within the chimney 20.

As will be understood, fluid products distilled from the oil shale contained within chimney 20 are recovered through well 18 or other recovery wells (not shown) drilled into chimney 20. Such products may be freed from the shale in a variety of ways including leaching or heating. For example, in the recovery of hydrocarbons from oil shale, a quantity of fuel is injected into the rubble contained within chimney 20 through well 18. Air is then pumped into chimney 20 and the fuel is ignited by an electrical spark or other conventional means. As combustion takes place within layer 24 of oil shale, the hot combustion gases produced cause liquification and/or vaporization of hydrocarbons contained in the shale and these hydrocarbon products are removed from chimney 20 through well 18, or other recovery wells (not shown) which enter the cavity at or near the bottom thereof. When the combustion of fragmented shale layer 24 contained within chimney 20 is substantially completed, additional oil shale from the formation 12 above chimney 20 is caved onto the hot ash at the base of apical void 21. Preferably, successive layers of the overlying shale formation are caved into chimney 20 as the combustion therein continues. This sequence of fragmented limited amounts of shale and treating them underground is repeated until the entire oil shale zone 12 located above chimney 20 has been treated.

By the present invention, methods are provided for caving layers of the overlying shale formation 12 into chimney 20 using controlled amounts of liquified explosive materials which are emplaced in fractures contained or induced in shale formation 12. Referring to FIG. 1, let it be assumed that shale formation 12 contains inadequate natural fractures for placement of the explosive materials to be used. By one technique of the present invention, fractures are induced in formation 12 at one or more levels from about 5 to 50 feet above the roof of chimney 20 through the utilization of conventional well fracturing techniques. When such conventional techniques are used, well bore 18 is plugged in a conventional manner, such as by the use of a packer 26, at a position above the roof of the chimney 20 and fracturing is initiated upon placement of a drill pipe 28 in well bore 18. During the fracturing operation, fracturing pressure is controlled using techniques well known in the art so as to produce a system of horizontally extending fractures 30, a significant portion of which are at least 1/4 inch in width and preferably 1/2 inch in width.

After fractures 30 have been propagated into formation 12, a liquid explosive having controlled, preselected viscosity, is pumped through conduit 28 and into fractures 30. In a preferred method of practicing this invention viscosity of the liquid explosive material used is chosen so that the liquid ex-

plosive material will enter only those fractures which are sufficiently wide to allow the effective detonation thereof. The liquid explosive used may be any suitable liquid explosive material such as liquid TNT or nitroglycerin, and the viscosity may be adjusted to a desired level by mixing the liquid explosive with well known and conventional high-viscosity slurries or fluids such as water gels, hydrocarbon gels, or hydrocarbon-water emulsions. In general, the viscosity of the liquid explosive slurry or gel should be adjusted to from about 100 to about 10,000 centipoise, and preferably from about 500 to about 1,000 centipoise, so that the liquid explosive material will enter only those fractures which are at least $\frac{1}{8}$ inch wide and preferably $\frac{1}{4}$ inch wide or wider. Since some gels exhibit a plastic behavior and shear at a boundary layer, these viscosity limits would not apply for such gels and will have to be determined on a case-by-case basis using techniques well known in the art. At viscosities below the foregoing, detonation of the liquid explosive material will be reduced due to the escape of portions of the material into "ineffective" fractures.

More specifically, each explosive material has a characteristic called its reaction-zone width. This width is the distance that detonation advances before the products of combustion expand by an appreciable percentage. Ideal detonation requires charges with diameters larger than the reaction-zone width. Effective confinement of the charge reduces the reaction-zone width. The reaction-zone width of nitroglycerin, for example, is substantially less than an inch. With sensitive detonator materials, like lead oxide and fulminate of mercury, the reaction-zone width is a small fraction of an inch. In addition to the necessity for emplacing the explosive in a sufficient thickness to exceed its reaction-zone width, enough force must be developed by the explosive to overcome the mechanical strength of the rock and cause fracturing and spalling. In the context of the present invention, the strengths which are of interest are primarily tensile strength and modulus of rupture, rather than compressive strength, since spalling is produced by the reflection of a tension shock wave from the free face of the rock overlying the chimney. Although these properties vary considerably from rock to rock, the effectiveness of the reflected strain wave in any case for spalling rock into the chimney is partially dependent upon the amount of explosive utilized, and this fact coupled with the reaction-zone width characteristic dictate the utilization of fractures which will allow the effective thickness of the explosive to be at least $\frac{1}{8}$ inch, and preferably at least $\frac{1}{4}$ inch.

After the liquid explosive slurry or gel is placed in fractures 30, drill pipe 28 is removed from well 18, the well is plugged at a point above fracture 30 in a conventional manner and the liquid explosive is detonated. Upon detonation, a layer of oil shale below fractures 30 is fragmented and falls into chimney 20 as shown in FIG. 2, forming a new layer of fragmented shale 32 on top of the previously treated layer 24.

Referring to FIGS. 3 and 4, an alternate technique for carrying out the present invention is illustrated. Again, let it be assumed that oil shale formation 12 does not include natural fractures sufficient for placement of liquid explosive materials. A plurality of J-shaped holes 34 are whipstocked in a conventional manner from the central well bore 18 laterally outwardly towards the outside periphery of chimney 20. A conventional packer or plug 35 is placed in the bottom of well bore 18 and a liquid explosive of adjusted viscosity is pumped into the J-shaped holes. To the extent that there are naturally occurring relatively wide fractures 36 intersecting J-shaped holes 34, the viscous explosive will also enter those fractures (see FIG. 4). J-shaped holes 34 facilitate the positioning of the explosive at the desired position above the roof of chimney 20. That is, holes 34 may be whipstocked from well bore 18 to desired positions adjacent to the roof of chimney 20 so that upon detonation of explosives within these holes and in any natural or artificially induced fractures which communicate therewith, a desired thickness or layer of the rock formation 12 is caved into chimney 20.

In FIG. 5 of the drawings, an alternate embodiment of the invention is illustrated. In this embodiment a series of horizontally extending fractures 40 having the desired minimum thickness have been propagated outwardly from well 18 using directional fracturing techniques well understood in the art. Thus, a predominant number of the fractures are selectively extended from one side of well 18 rather than in a generally symmetric pattern therefrom. By using such an asymmetric fracture pattern rather than a more conventional symmetric fracture pattern the keystone effect inherent in arch structures is overcome, with an attendant increase in the amount of rock spalled into chimney 20. Drilling a fracturing hole off center would produce a similar effect.

When naturally occurring fractures are sufficiently well developed, and are of sufficient critical thickness to permit them to be utilized to obtain the desired spalling effect, they may also be employed for emplacing the liquid explosive material utilized in practicing the invention.

In addition to the fracturing pressure and viscosity control which has been described as one technique for limiting and adjusting the mobility of the liquid explosive, other techniques can also be used for insuring that only properly sized fractures are utilized for explosive emplacement. Thus, where a significant number of hairline and/or very thin fractures intersect the main fractures, the known oil field technique of employing lost circulation materials can be utilized to prevent bleed off or dissipation of the liquid explosive material into these narrow "noneffective" fractures. The materials useful in conventional lost circulation techniques can generally be used for the described control function in the present invention, such materials including bentonite or montmorillonite clays, as well as a great many other well-known materials.

It is also necessary at times to prevent closure or healing of artificially developed fractures prior to the time that the liquid explosive can be emplaced in the fractures, or even after the liquid explosive has been placed therein. It will be apparent that if the fractures undergo closure or healing before the explosive has been placed, this may result in the width of the fracture being decreased below the critical limit for effective detonation as hereinbefore described. Moreover, with some types of explosives, healing or closure of the fracture may result in predetonation of the explosive due to the imposition of excessive pressure thereon. For the purpose of avoiding the occurrence of both these difficulties, propping materials used in conventional oil and gas production can be employed. Such materials conventionally include sand, gravel, glass beads, walnut hulls, and many other particulate materials. Preferably, propping materials employed in the present invention comprise small spheres or even solid particles of compressed explosives. Any particles used for the purpose of preventing healing or closure of the fractures should have sufficient compressive strength to hold the fractures open, and should be of proper size to allow their emplacement during the fracturing operation and to permit sufficient interstitial voids to remain between the particles so that the critical detonation dimension of the explosive materials may be attained.

Although certain preferred embodiments of the invention have been hereinbefore described as examples of the practice of the invention, it is to be understood that various changes and innovations can be effected in the steps and parameters disclosed without departing from the basic principles underlying the invention. Changes and modifications of this type are therefore deemed to be circumscribed by the spirit and scope of the invention except as the same may be necessarily limited by the appended claims or reasonable equivalents thereof.

What is claimed is:

1. A method of spalling overlying rock into an underground chimney comprising the steps of:
 - a) emplacing liquid explosive material in fractures extending generally horizontally into the rock above the chimney and having a sufficient vertical width to allow effective detonation of the explosive, while concurrently excluding the liquid explosive from fractures having a lesser vertical

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width by adjusting the viscosity of the liquid explosive;
and
detonating said liquid explosive material, thereby causing a
portion of the overlying rock to be fragmented and to fall
into said cavity. 5
2. A method of recovering hydrocarbons from a subterranean
formation comprising:
drilling a well bore through the formation;
placing an explosive in the well bore at a situs adjacent to
the formation; 10
detonating the explosive to form a chimney extending at
least to the lower portion of the formation;
subjecting the rock of the formation above the chimney to
hydraulic pressure which is controlled to produce a
system of fractures which are at least 1/8 inch in width; 15
injecting a pumpable explosive mixture into said fractures
while controlling the viscosity of the pumpable explosive
mixture to prevent its entering fractures having a vertical
width of less than 1/8 inch;
detonating the pumpable explosive mixture in the fractures 20
to spall rock into said chimney; and
treating broken rock spalled into the chimney to recover
hydrocarbons therefrom.
3. A method of spalling overlying rock into an underground
chimney comprising the steps of: 25
forming an asymmetrical pattern of fractures in the earth

above said underground chimney;
emplacing liquid explosive material in the portion of such
fractures having a sufficient vertical width to allow effective
detonation of the explosive while concurrently excluding
the liquid explosive from fractures having a lesser
vertical width; and
detonating said liquid explosive material, thereby causing a
portion of the overlying rock to be fragmented and to fall
into said cavity.
4. A method of recovering hydrocarbons from a subterranean
formation comprising:
drilling a well bore through the formation;
placing an explosive in the well bore at a situs adjacent to
the formation;
detonating the explosive to form a chimney extending at
least to the lower portion of the formation;
subjecting a portion of the formation above the chimney to
hydraulic pressure to form an asymmetric fracture pattern
while controlling the hydraulic pressure to form fractures
which are at least 1/8 inch in width; 15
injecting a pumpable explosive mixture into said fractures;
detonating the pumpable explosive mixture in the fractures
to spall rock into said chimney; and
treating broken rock spalled into the chimney to recover
hydrocarbons therefrom. 20

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