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[54] METHOD OF BULKING OR CAVING A VOLUME OF SUBSURFACE MATERIAL

22 Claims, 3 Drawing Figs.

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[51] Int. Cl. E21b 43/26
[50] Field of Search 166/283, 281, 280, 247, 300, 299, 302, 308, 260

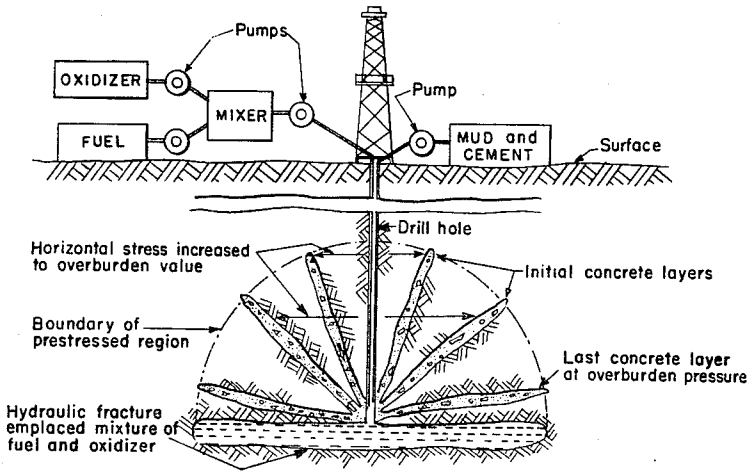
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ABSTRACT: A volume of subsurface material is bulked or caved by generating a gas pressure in the base of the volume in a time of from about 1 to about 10 seconds having an energy input sufficient to lift the overburden material to an extent such that material falls or caves and leaves a chamber having a generally hemispherical roof containing the caved material and providing an interconnected void space. The gas pressure to obtain what may be termed a quasi-static lifting of the overburden material may be generated by shock ignition of a volume-burning propellant, by flame front ignition of a volume-burning propellant, by combustion of an oxidizer and fuel delivered separately and mixed in place in the base of the volume, or by rapid delivery to the base of the volume of a previously stored gas under high pressure.



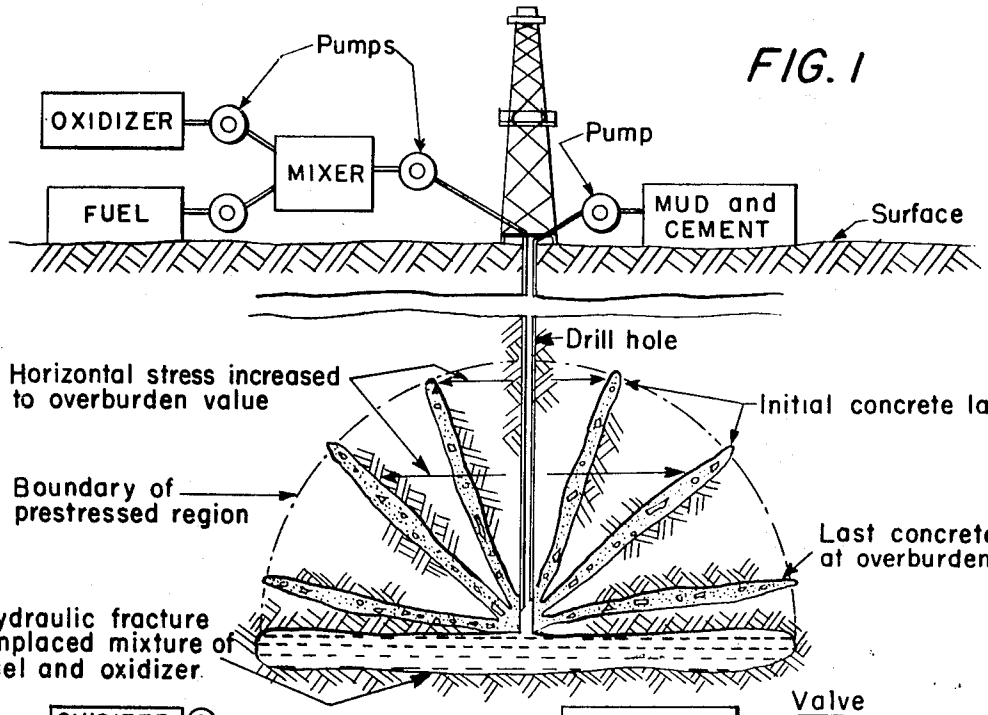


FIG. 1

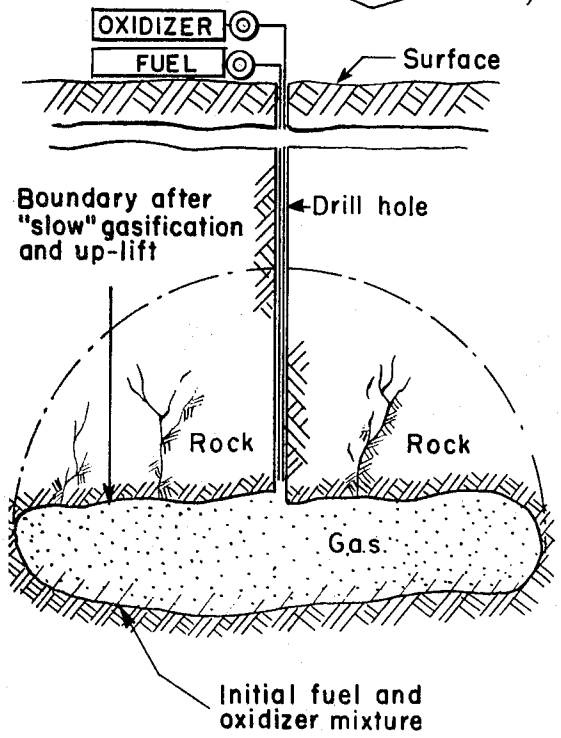


FIG. 2

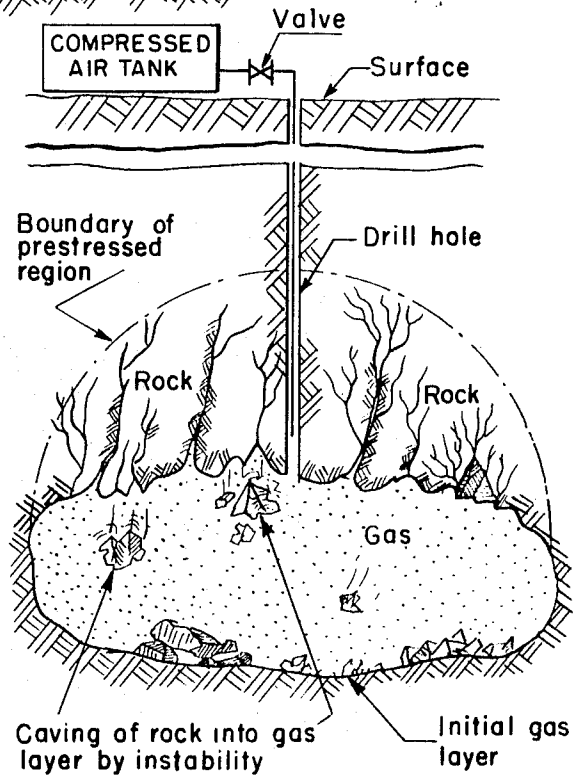


FIG. 3

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METHOD OF BULKING OR CAVING A VOLUME OF SUBSURFACE MATERIAL

This application is a continuation-in-part of application Ser. No. 691,295, filed Dec. 18, 1967, now abandoned.

BACKGROUND OF THE INVENTION

The present invention relates to the creation of underground interconnected void space, for the purpose of relative ease of fluid or gaseous communication with large volumes of underground material and in particular to a novel form of achieving this interconnected void space by rapid-burning solid, liquid, or gaseous oxidizer-fuel mixtures and novel methods of emplacement of said materials.

The technique of creating underground interconnected void space is well known in the oil industry as "hydraulic fracturing" and is used for the stimulation of the oil or gas production from the underground formations that do not have a high enough porosity to permit sufficient flow at the available fluid or gaseous pressure. The customary procedure requires that a fluid under high pressure is pumped down the well bore at a sufficient rate such that the overpressure underground cracks ("fractures") the rock formation and the subsequent fluid flow carries hard particles into the crack and "props" it open so that later fluid or gas can flow back through the fracture to the well bore. The process of hydraulic fracturing is a useful and efficient means of stimulating oil and gas production and is widely used throughout the world. A possible improvement to the process of hydraulic fracturing is the use of an explosive for creating the underground pressure required for fracturing the rock. This process requires emplacement of relatively large volumes of explosive underground usually in liquid or slurry form and then detonating the explosive so that the pressure corresponds released almost simultaneously. The extreme limit of the process of explosive hydraulic fracturing is exemplified by the underground nuclear explosion. Since the under ground nuclear explosion has been studied and analyzed in greatest detail, it will be used as the prime example of explosive fracturing, and the departure of the present invention will later become apparent.

NUCLEAR EXPLOSIVE FRACTURING

The extreme heat of an underground nuclear explosion generates a pressure infinitely above the overburden pressure and a spherical bubble or cavity rapidly expands away from the point of detonation. As the bubble expands the gases inside the cavity (vaporized rock and steam) decrease in pressure according to the well-known adiabatic law until the pressure becomes no greater than that due to the overburden of rock and soil. The growth of the cavity would cease at this point were it not for the momentum corresponding to the rapid velocity at which the cavity initially expanded. The kinetic energy corresponding to this expansion velocity is comparable to that in the volume of gases when the gas pressure is the same as the overburden. Consequently, the cavity overshoots the equilibrium radius and finally oscillates (highly damped) around this radius until becoming static. The equilibrium static underground spherical cavity remains in this form until the gases cool by heat conduction or leak into the surrounding rock. Because a nuclear explosion is so large, the time for cooling and leaking may be several minutes, whereas for a more conventional explosion of moderate size the cooling and leaking time may be very short indeed (a second or less). Nevertheless, after cooling and leaking, when the gas pressure has fallen well below overburden pressure, the cavity may remain standing in its spherical form for times of minutes to hours, but after this somewhat uncertain time the roof of the cavity starts to fall because the stresses do not distribute themselves like a classical stone arch, but instead occasional pieces of rock find themselves in tension and so fall or cave. (The exception to this is an explosion in rock salt where the peculiar properties of the material cause a bridging of the stresses and caving does not occur as readily). When pieces of the roof of the cavity fall down, they release other pieces and

caving " of the cavity proceeds. This process of caving is analogous to the instability that takes place whenever a heavy fluid is supported by a lighter one (scientifically called "-Taylor instability"); the heavy fluid falls in blobs into the lighter one, and unstable mixing takes place the same as if one tries to support water with air pressure. In the case of the rock, however, the mechanical strength of the material prevents a fluid blob from forming and only "chunks" defined by previous cracks can fall or cave out of the roof of the cavity. The frequency of the cracks and the lateral stress or bridging, as in a stone arch, determines whether the "chunk" will fall. In the case of a spherical roof of usual rock unstable caving occurs provided the mean spacing of cracks is small compared to the radius of the sphere. If the roof were flat, caving would occur much more readily as witnessed in mines where "roof bolts" are used to distribute the stress more uniformly in the rock above. In the case of the explosively formed cavity the many cracks formed during the initial expansion assure that caving occurs relatively easily despite the near perfect arch of the roof.

BULKING

Once caving has commenced, it continues either until the bulking of the caved rock fills up the progressively enlarging cavity and the bulked rock reaches the roof, or until a rock stratum is reached that has a crack spacing as large as the reduced roof radius. This usually leads to a volume of caved rock about four times the initial spherical cavity volume. For the large energies available from nuclear explosions, this volume of broken rock may be very large, several million tons, and aside from radioactivity it is in an ideal form for further processing by in-place mining methods such as chemical leaching, or oil extraction by retorting. From the standpoint of exposing large volumes of rock, however, the energy of the nuclear explosion has not been used efficiently.

EFFICIENCY OF BULKING

The volume of space between the exposed rock is relatively large, namely, 25 percent, whereas the fissures that are sufficient to interconnect a gas or oil reservoir may be as small as 1/10 percent of the total volume. In addition, a large fraction (up to 50 percent) of the energy of the explosion has gone into heating an melting the rock. An additional 25 percent has gone into shock crushing and dynamical motion of the cavity. Finally, the heat that creates the gas pressure that forms the cavity uses a gas (vaporized rock and steam) that has a very large latent heat so the remaining heat in the gas when the cavity has reached its static equilibrium size is roughly eight times larger ($1/(\alpha-1)$, α= ratio of specific heats) than the energy corresponding to the displacement volume of the cavity. Consequently, by improving on these various factors it is conceptually possible to expose rock by interconnected voids very much more efficiently than with nuclear explosives. The object of this invention is to perform this function using slow, or quasi-static energy release, and thus achieve a far more efficient fracturing and bulking of the rock.

CAVING GEOMETRY

The ideal geometry for rock caving is one in which the rock is supported over a large area by a relatively flat lense or layer of gas; in this case a light fluid, the gas, supports a heavy quasi-fluid, rocks with many cracks, and so "Taylor instability" caving in not likely to take place. The many cracks means that the crack spacing must be small compared to the relatively large horizontal dimension of the gas layer. The vertical height to which the caving will progress is determined both by the thickness of the gas layer as well as the horizontal dimension. Once the vertical caving has reached a height equal to the horizontal radius, the near spherical configuration will cause bridging and further caving will be inhibited. (A spherical gas "layer" caves to a height of only four times the initial radius). In addition, the initial fracture heterogeneity will determine

the bulking ratio as caving proceeds. However, if the crack spacing is large compared to the gas layer thickness (the crack spacing is also small compared to the gas layer radius) then one would expect that the chunks of rock would slip a relatively small distance before permitting the next one to move. In this case, the bulking fraction should be significantly less than the relatively large 25 percent corresponding to the caving of a spherical cavity. If, in addition, the initial fractures that were preferentially vertical were preferentially opened and lubricated, a still more favorably small bulking ratio might be achieved. The proposed method of relatively slow pressure release and the proposed method of oxidizer-fuel emplacement should tend to augment each of these factors.

EXPLOSIVE PROBLEMS

If a conventional explosive like TNT, gels or high-velocity slurries (ammonium nitrate, oil and aluminum) were used to create the required gas layer, the first and largest inefficiency that would occur would be the initial crushing of the rock by the very high detonation pressure (400 kilobars) compared to the relatively weaker crushing strength of the rock (75 to 100 kilobars). Thus the major fraction (75 percent) of the explosive energy would be lost from "lifting" the overburden rock. Next, of the remaining 25 percent useful energy almost all of this will do work on lifting the overburden rock at a pressure that is large (75 to 100 kilobars) compared to the overburden pressure (350 bars at 5,000 feet depth), so that the kinetic energy will give rise to an overshoot that is about equal to the equilibrium displacement. The result is a fraction of this energy is emitted as a seismic wave (50 percent) and an additional loss occurs due to the rebound and recompression of the gas to a high temperature with the attendant loss by thermal conductivity to the rock. The efficiency factor to be gained by a relatively slow lift of the overburden rock is perhaps as large as 10 if not more.

QUASI-STATIC LIFTING

Consequently, a major factor of efficiency can be obtained by lifting the rock slowly. Slowly means the pressure must be raised in a time not significantly shorter than the accommodation time of the rock configuration. In the case of the formation of a gas layer thin compared to its horizontal radius, the movement of the rock will occur principally within a spherical volume corresponding to the radius of the layer. The accommodation time then corresponds to several times the traversal period of sound across the spherical volume. Since the radius must be large compared to the average crack spacing this means that most practical operations will be performed where the radius of the layer will be several tens up to 100 meters in diameter. Since the speed of sound in rock is roughly 5 kilometers per second, the traversal period will be several tenths of a second. Therefore, the pressure must be created in a time not much less than a second at any one location. (The corresponding time for a fast explosive is several microseconds and so unsuitable by six orders of magnitude).

ROCKET PROPELLANTS

As a consequence, one naturally looks at the technology of rocket propellants where relatively rapid combustion rates are achieved. Unfortunately, however, heterogeneous or homogeneous premixed propellants, usually called solid propellants, burn with a flame front that progresses into the propellant at only several centimeters per second, requiring several thousand seconds to burn to completion to a radius of 100 meters. Ordinary solid propellant technology, therefore, is several orders of magnitude too slow for the rock caving requirements.

MAXIMUM BURN TIME

Before proceeding with the solutions to these problems, the maximum burn times should be considered. Two losses occur when the gas is generated too slowly; namely, the gas can leak away through fissures as it is generated and, secondly, the high temperature or heat content of the gas can be conducted into the rock, and hence the pressure will dissipate before it has lifted the overburden. Both these losses should become important in several tens of seconds, so that the burn time of the "-propellan" should occur within 1 to 10 seconds.

SUMMARY OF THE INVENTION

In accordance with the invention, a subsurface interconnected void space is obtained by the rapid burning of solid, liquid, or gaseous fuel-oxidizer mixtures emplaced in a subsurface material. A separate fuel and oxidizer, a fuel-oxidizer mixture, or a compressed gas is used to lift the overburden material relatively slowly, i.e., in from about 1 to about 10 seconds, so that the overburden material caves into the cavity formed by the gas pressure.

The invention also provides a technique for prestressing the ground above a selected strata to be bulked for the purpose of preparing it for bulking or for other operations in the strata, such as mining or establishing a storage space. The technique permits the "engineering" of underground stress fields. Prestressing is accomplished by sequentially fracturing an underground zone with a cement slurry or other setting or partially setting material, such as self-propping mud.

DESCRIPTION OF THE DRAWINGS

For a better understanding of the invention, reference may be made to the following description of exemplary embodiments, taken in conjunction with the three FIGURES of accompanying drawings, each of which illustrates diagrammatically a mode of carrying out the invention.

DESCRIPTION OF EXEMPLARY EMBODIMENTS

Method of Gasification:

Described below are four variants of the method, according to the invention, for generating the quasi-static but rapid gasification required for efficient rock caving. 1. A heterogeneous mixture of fuel and oxidizer can be ignited by the passage of a weak detonation front or strong shock which releases only a small fraction (less than 10 to 20 percent) of the ultimate heat of combustion. The remaining larger fraction of the heat of combustion is released only as the heterogeneous regions of fuel and oxidizer mix and burn. The rate of this secondary burn that releases the major fraction of the energy is governed by the size of the grains of each component. It is referred to as shock ignition of a volume-burning propellant. 2. A heterogeneous mixture of fuel and oxidizer can be ignited by the rapid progression of a flame front over a relatively large area and subsequent burn through a relatively thin layer. In addition, if the mixture is a fluid (or slurry), a bubble ignited within the mixture will propagate first by flame progression over the inside surface of the bubble and then the expansion of the surface of the bubble due to the pressure generated by burning. Such bubble growth and subsequent coalescence of bubbles leads to the same final limit of rapid flame front ignition and subsequent burn of relatively thin web between bubbles. The aforementioned "Taylor instability" occurring when the fluid mixture is accelerated by the lighter combustion product gases will create the bubbles. The combined effect of "Taylor instability" bubble creation, and flame front progressive ignition is referred to as flame front ignition of a volume-burning propellant. 3. The separated oxidizer and fuel can be pumped rapidly underground and burned in place at a rate determined by the pumping rate. This is exactly the method used in a standard liquid fuel rocket, except underground the preservation of the combustion chamber is not important For deep holes and very large volume the pumping problem becomes impractical. However, for relatively shallow bulking problems as for instance the augmentation of the porosity of ore dumps for leaching, such a solution as this might be cheaper than heterogeneous propellants. (Liquid ox-

ygen is a cheaper oxidizer than the standard "solid" oxidizers such as ammonium perchlorate, etc.) This method will be referred to as local combustion of separated oxidizer and fuel. 4. Finally, the gas required to lift or bulk the underground material can be supplied directly as compressed air provided the depth is small, less than about 100 feet, and the pipe diameter is large, and further, the air pressure is many times overburden pressure so that very rapid gas flow is achieved. One envisages that the gas would be stored initially in a tank at high pressure with a quick-opening, large diameter valve connected directly to the down hole casing. This method will be referred to as compressed air bulking.

Volume-burning propellants:

Regardless whether volume burning of a heterogeneous propellant is achieved by a weak detonation front spreading, the time of burn is limited in both cases by the particle size of either oxidizer or fuel. The characteristic time is roughly the time for sufficient heat to penetrate the larger particles to vaporize them. This time is approximately

$$\tau \cong (\rho c / K)(d^2/4)$$

where K is the thermal conductivity, ρ is the density, c is the specific heat per unit mass and d is the particle size. For 0.2 cm. solid particles of $KC10_3$, or NH_4C10_3, $K \cong 10^{12}$ cal./deg. cm. sec., the time should be roughly 1 second. For an oxidizer that detonates strongly when driven hard enough (NH_4NO_3) the mixing of oxidizer with liquid fuel (oil) may occur on a time scale of the turbulent flow of the hot oxidizer gas which is very much more rapid. Indeed, it occurs within the time of detonation (^{14} to 10^{13} seconds). Hence the slurry-type explosives using somewhat similar (but different) materials burn to completion rapidly and therefore "detonate."

Therefore, the detonation properties of the oxidizer become an important factor in determining the slow volume-burning properties of the propellant. Ammonium perchlorate, NH_4C10_3, or potassium perchlorate, $KC10_3$, are the preferred solid oxidizers.

PROPELLANT EMPLACEMENT

In order to achieve the quasi-static lift of several feet of the ground over a large area by combustion gases, the preferred geometry for the initial distribution of the oxidizer and fuel is a disc several tens to hundreds of feet in diameter and thickness of one-fourth to 1 inch.

The lift, L, achieved with a layer thickness, D, of fuel-oxidizer combination can be calculated front the formula

$$D \epsilon (\alpha - 1) = L\, h\, g \langle \rho \rangle = L\, P_0$$

WHERE ϵ is the energy release per unit volume of fuel-oxidizer combination, (5,000 to 10,000 joules per cm_3.), α is the effective ratio of specific heats 1.2 to 1.4, h is the burial depth, g, the acceleration of gravity, $\langle \rho \rangle$, the average overburden rock density, and P_o is the overburden pressure. The simplest method of achieving this emplacement geometry is by fluid fracturing of the rock structure using the combined fuel-oxidizer as the fracturing fluid. If the rock structure is highly bedded in layers of relatively strong rock and the depth less than 3,000 to 4,000 feet, then the recorded fracture pressures observed in the oil industry almost always correspond exactly to the overburden pressure. This is the pressure that one expects if a horizontal fracture is occurring, because the fluid must support the force of overburden rock pressure with negligible bridging or beam effect. At greater depths or in regions that are not tectonically relaxed, the fracture fluid pressure varies randomly mostly between one-third to two-thirds of overburden pressure. This pressure behavior is what would be expected if the underground were supported by columns of rock that were packed together with a "packing pressure" that varied from one-third to two-thirds of the vertical overburden pressure on the columns. As a consequence, a hydraulic fluid under pressure would more readily penetrate between the columns rather than pumping them up vertically. In order to achieve the horizontal fracture in a medium initially in columnar support, it is first necessary to pack the columns together with a greater pressure than occurs vertically.

"Engineering" Underground Stresses:

Deep underground the ground is supported like columns in that the vertical stress is large, i.e., "the overburden stress," and, in general, corresponds to just the weight of the overburden material. The horizontal stress, on the other hand, is in general less than the overburden by roughly one-third to one-half. In certain geologically active regions as during mountain building, this may not be so, but in tectonically relaxed regions oil well fracturing at 5,000 feet depth and greater indicates the ratio of overburden to formation fluid acceptance pressure to be roughly two-thirds. This is equivalent to surrounding our supporting columns of rock with a fluid two-thirds as dense as the column materials. Actually—and only rarely—would this picture be true. Instead, the pressure in the rock is anistropic and if one injects a fluid underpressure it will spread the rock sideways and not lift it. This is called vertical fracture.

By way of contrast, the archways of stone in a building near their center (keystone) have a horizontal stress (sideways thrust) large compared to the vertical stress (weight). As a consequence, the arch supports—or "bridges"—a horizontal area.

It is the object of the process of sequential cement fracturing to create such a bridging of stress underground. By pumping in a setting fluid—first the ground is spread sideways a little and the fluid reaches out as a vertical crack—spreading the "columns" sideways slightly and compressing them sideways slightly. After the cement is set, a repeated series of such sequential fracturing an setting will continue to increase the sideways stress until it becomes greater than overburden pressure. (The volume of cement required is roughly volume of rock effected times one-third the ratio of the overburden pressure to Young Modulus for rock. At 5,000 feet depth, this would be about 1.3×10^{14} of the rock volume effected).

When the horizontal stress is greater than the vertical, the rock appears roughly like an arch or solid bridge. When further fluid is pumped under such a bridge, it tends to lift the bridged region of rock as a unit rather than finding vertical cracks to escape. In other words, the next additional fluid should tend to flow horizontally since this is the direction of least pressure resistance.

By placing the spheres of stress (regions of sequential fracturing) in turn in the shape of a hemishperical shell, very large areas (domes) of stress can be created.

In addition to preparing for bulking by the techniques described above, the engineering of the underground stress field into prestressed shapes by the method of sequential fracturing can also be used in operations such as, for example, the following: 1. If a large cavern of rock is to be mined underground, prestressing of the final roof contour by intially—before mining—sequential fracturing will create the arch stresses before the removal of the rock thus allowing a far safer mining operation and the creation of far larger underground caverns. 2. If storage space is required for underground gas, then prestressing of the overburden will "seal" the "roof" against gas leakage so that when gas is pumped into the ground below such a prestressed region ("roof") the gas will lift the overburden (horizontal fractures) rather than creating vertical fractures that lead to gas escape from the surface.

An example of this process of "sealing" the overburden (creating horizontal stress) by the sequential fracturing with a setting fluid exists in nature. People who observe or live in fear of volcano eruptions are beset by the random way the flows break out of the mountain. An eruption or flow never seems to break out of the same place—or side of the mountain—more than a few times in succession. The eruption always seems to give up the last "weak point" in favor of a new and unknown one. What is evidently happening is that any given flow increases the horizontal stress; the hot lava sets when it cools and hence seals in a natural plug. It might require more than one eruption, but after several, the horizontal stress should then be greater than elsewhere and so a new "weak point" becomes the new eruption. This is important for gas storage because whenever a leak is detected at the ground level, a

relative straightforward mechanism is available to seal the leak; namely, drilling and sequential fracturing, etc. 3. Fracturing of oil formations to stimulate oil and gas flow is usually accomplished by fracturing with a fluid with a crack propping agent, beads, etc. Below 5,000 feet the fractures are almost universally vertical. If they could be made horizontal a larger recovery would be possible. By sequential concrete fracturing above the oil or gas bearing zone a prestressed roof can be created such that a standard fluid fracture below and within the oil or gas formation should extend horizontally a distance corresponding to the prestressed roof. 4. For inplacement of leaching of minerals one wants interconnected void space within the rock. This may be achieved by an explosive lifting of the overburden to create the voids. The explosive, however, must be placed in a horizontal layer beneath the region to be bulked. Hence, the "roof" of the region should be prestressed so that a liquid explosive or a propellant-type gas source can be placed horizontally beneath the region to be bulked.

The reason for using cement or partially setting and self-propping mud is so that the fluid in the vertical cracks does not continue to migrate instead of remaining fairly local (several hundred feet) from the point of injection. By remaining local and building up layer after layer in the vertical cracks, the horizontal stress will accumulate due to the added volume. If Y is Young modulus and P is the difference between overburden pressure, P_0, and fracture pressure, P_f, then the fractional volume than must be added becomes

$$V_f = \Delta P / Y.$$

For typical rocks and depths 5,000 to 10,000 feet, the fractional volume of mud or cement that must be added to raise the fracture pressure to overburden is 10^{13} or less. For bulking as described above, the combined oxidizer-fuel, on the other hand, must be enough to raise the same volume something like 1 percent to 10 percent so that subsequent caving would give a bulking of 10^{13} of the total volume. The volume of fuel and oxidizer required at 5,000 to 10,000 feet is roughly 1 to 2×10^{13} of the same rock volume so that the horizontal fracture required for oxidizer-fuel emplacement is roughly the same volume as the vertical fractures filled with mud or cement.

EXEMPLARY EMBODIMENT

In one exemplary embodiment of this invention, referring to FIG. 1, a cased drill hole is made to the rock stratum that is to be caved. A heavy mud such as one incorporating barite or iron oxide is used to fracture the formation. If the fracture pressure is equal to and remains at overburden pressure, then it is presumed that a horizontal fracture has been formed and no further mud is required. If the pressure is less than overburden pressure, more mud is added to continue fracturing until the pressure rises to overburden, or until something like one-half the calculated volume is added that theoretically should raise the horizontal stress to overburden value. If the fracturing pressure has not risen significantly by the time this volume is added, it implies that the mud is too fluid and too little "-bridging" and propping of the fractures (presumedly vertical) is taking place. In this case, a setting cement must be added so that the fractures will remain propped. Additional fractures should then be made with cement (waiting for periods such that the cement will set) so that the vertical fractures will be additionally propped with each additional cement fracture. When the fracture pressure reaches overburden pressure for a series of repeated cementing fractures, then it can be presumed that some of these are occurring in the horizontal direction. At this point the combined oxidized fuel mixture is pumped down the hole at a volume rate higher than that used for fracturing and preferably with sufficient viscosity (for example heavy fuel oil with ammonium perchlorate or potassium perchlorate) so that some self-propping of the fracture occurs. If the heavy oil requires some modest heat before it flows readily enough for pumping, then upon cooling in the fracture, a thicker layer will be formed and the pressure, temperature viscosity, and pumping rate will control the thickness f the layer propping the fracture. The fuel oxidizer mixture is then ignited by using a larger booster charge, preferably again, a fracture emplaced high velocity slurry explosive. Large means up to 10 percent of the volume of the combined fuel-oxidizer mixture as experience dictates is required to obtain either the necessary volume ignition by shock or flame front spreading. The optimum fuel-oxidizer ratio is stoichiometric, but large excesses of fuel (e.g., oil) can be used to obtain the fluid properties desired.

According to other embodiments the method of local combustion of separate fuel and oxidizer or the method of compressed air bulking, a relatively large hole is drilled and cased to the desired depth, and the fuel and oxidizer are pumped through separate lines to the bottom of the hole in a time of several seconds (see FIG. 3), or similarly the compressed air is released form a reservoir in several seconds (see FIG. 3). The size of the drill hole, casing, depth, volume to be delivered and pumping pressure or air reservoir pressure determining whether the fluid or gas can be delivered to the bottom of the hole in the required several seconds. If the hole size, pump size, or air pressure become too large to be practical, then, of course, the previous method of fracture emplaced fuel-oxidizer mixture can be used.

The oil industry has amassed a large body of knowledge concerning fracturing technology that will allow many variation upon the procedures described above. Accordingly, variations and modifications of the invention as hereinabove described that are within the skill of the art are intended to be included within the spirit and scope of the invention, as defined in the appended claims.

I claim:

1. A method of bulking or caving a volume of subsurface material comprising the step of generating a gas pressure at the base of the volume in a time of from about 1 to about 10 seconds and with an energy input such that the overburden material is lifted to an extent sufficient to enable such overburden material above the said base to fall or cave and leave a chamber having a generally hemispherical roof and containing caved material and providing an interconnected void space the gas pressure being generated by slowly gasifying a heterogeneous mixture of a fuel and an oxidizer of the fuel previously emplaced in a layer at the base of the volume.

2. A method according to claim 1 wherein the fuel-oxidizer mixture constitutes a volume-burning propellant and is gasified by propagating through it a weak detonation front or strong shock to provide shock ignition and secondary burn.

3. A method according to claim 1 wherein the fuel-oxidizer mixture is a fluid and is gasified by generating a rapidly progressing flame front and establishing Taylor unstable mixing to provide flame front ignition of the mixture.

4. A method according to claim 3 wherein the gas pressure is generated by introducing separately at the said base of the volume a fuel and an oxidizer for the fuel that oxidizes the fuel upon mixing therewith under the environmental conditions.

5. A method of bulking or caving a volume of subsurface material comprising the steps of creating a generally horizontal fracture at the base of said volume, emplacing in the fracture a layer of a heterogeneous mixture of a fuel and an oxidizer for the fuel capable of relatively slow gasification, and igniting the mixture to generate by burning of the mixture a gas pressure in a time of from about 1 to about 10 seconds with sufficient energy to lift the overburden material above the fracture such that the overburden material falls or caves and leaves a generally hemispherical chamber containing caved material and providing an interconnected void space.

6. A method according to claim 5 wherein the fracturing and emplacement steps are carried out simultaneously by fracturing with the fuel-oxidizer mixture.

7. A method according to claim 5 wherein the fracturing is accomplished prior to emplacing the fuel-oxidizer mixture.

8. A method according to claim 7 wherein the material is first repeatedly fractured with a setting or partially setting and self-propping fracturing fluid to redistribute the stresses in the material and ensure a final substantially horizontal fracture.

9. A method according to claim 5 wherein the fuel-oxidizer mixture constitutes a volume-burning propellant and is gasified by propagating through it a weak detonation front or strong shock to permit shock ignition and secondary burn of the propellant.

10. A method according to claim 9 wherein the fuel is a fluid hydrocarbon, and the oxidizer is a member selected form the group consisting of ammonium perchlorate (NH_4C10_3), potassium perchlorate ($KC10_3$), and combinations thereof.

11. A method according to claim 5 wherein the fuel-oxidizer mixture is a fluid and is gasified by generating a rapidly progressing flame front igniton of the mixture.

12. A method of obtaining control and redistribution of stresses in a volume of underground material comprising the step of sequentially and repeatedly fracturing the material in said volume along at least two nonparallel fracture zones diverging generally upwardly and outwardly from a zone of a well bore with a setting or partially setting fracturing fluid.

13. A method according to claim 12 wherein the fracturing fluid is a setting cement.

14. A method according to claim 12 wherein the fracturing fluid is a self-propping and bridging mud.

15. A method according to claim 12 wherein the fracturing fluid is permitted to set after each fracture operation.

16. A method of obtaining control and redistribution of stresses in a volume of underground material comprising the steps of repeatedly pumping into the volume from a point in a well bore passing through the volume a setting or partially setting fluid under a pressure sufficient to generate a fracture diverging generally upwardly and outwardly from the said point in the well bore, and allowing the fluid to set between each of the said repeated pumping steps, thereby successively to spread portions of the volume of material generally laterally to compress such portions and generate lateral stresses in the volume of material to render the material in the volume essentially self-supporting.

17. A method according to claim 16 wherein the fluid is a self-propping and bridging mud.

18. A method according to claim 16 wherein the fluid is a self-propping and bridging mud.

19. A method according to claim 16 wherein the total volume of fluid pumped into the volume of material by the repeated pumping steps is approximately equal to the volume of the said volume of material times one-third the ratio of the overburden pressure at said point in the well bore to Young's Modulls for the material.

20. A method according to claim 16 and further comprising the step of mining underground strata below said volume of material after completing the repeated pumping and setting steps.

21. A method according to claim 16 and further comprising the step of pumping a fluid into the ground below said volume of material for storage thereof after completing the said repeated pumping and setting steps.

22. A method according to claim 16 and further comprising the step of forming a standard fluid fracture in a zone below said volume of material to facilitate recovery of fluid from said zone after completing the said repeated pumping and setting steps.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,616,855 Dated November 2, 1971

Inventor(s) STIRLING A. COLGATE

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 34, "corresponds" should be --is--; Column 2, line 1, insert a quotation mark (") before "caving"; line 45, "an" should be --and--; line 66, "in" should be --is--; line 66,"means" should be --mean--; Column 4, line 7, "propellan" should be --propellant--; line 60, after "of" insert --the--; line 71, after "important" insert a period (.); Column 5, line 20, the equation should be --$\tau_0 \simeq \frac{\rho c}{K}\frac{d^2}{4}$; line 23, "$10^{12}$" should be --$10^{-2}$--; line 30, ($10^{14}$ to 10^{13} seconds) should be --(10^{-4} to 10^{-3})--;line 46, "front" should be --from--; line 48, "WHERE" should be --where--; line 48, "εis" should be --ε is--; line 48, "release" should be --released--; line 49, "cm_3" should be --cm^3--; line 66, delete "of"; line 71,"between" should be underscored; Column 6, line 16, "not" should be underscored; line 29, "an" should read --and--; line 34, "10^{14}" should be --10^{-4}--; line 50, "intially" should be --initially--; Column 7, line 8, "above" should be underscore line 32, "10^{13}" should be --10^{-3}--; line 36, "10^{13}" should be --10^{-3}--; line 37, "10^{13}" should be --10^{-3}--; line 38, after "fracture" insert --volume--; line 75, "f" should be --of--; Column 8, line 16, "form" should be --from--; Column 9, line 7, "form" should be --from--; Column 10, line 8, "self-propping and bridging mud" should be --setting cement--.

Signed and sealed this 16th day of May 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents