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[54] LIQUID EXPLOSIVE FOR WELL FRACTURING

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[21] Appl. No.: **110,315**

Related U.S. Application Data

[63] Continuation of Ser. No. 765,113, Oct. 4, 1968, abandoned.

[52] **U.S. Cl.** **166/299,** 166/308, 166/311

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

[58] **Field of Search** 166/299, 291, 153, 308, 305, 166/311; 102/23, 20; 86/20.3

[56] **References Cited**

UNITED STATES PATENTS

2,124,710	7/1938	Pipes	166/153
2,402,588	6/1946	Andresen	166/291 X
2,676,662	4/1954	Ritzmann	102/23 X
2,708,876	5/1955	Nowak	166/299
2,867,172	1/1959	Hradel	102/23
2,892,405	6/1959	Chesnut	166/299
2,892,406	6/1959	Hradel et al.	102/23
3,075,463	1/1963	Eilers et al.	166/299
3,191,678	6/1965	Hinson	166/153 X
3,311,678	3/1967	Brock et al.	86/20 X
3,561,532	2/1971	Fletcher et al.	166/299

Primary Examiner—David H. Brown

[57] **ABSTRACT**

A cap insensitive liquid explosive as described which is particularly useful for fracturing a formation containing a network of narrow fissures adjacent a well bore in a well or to increase its productivity, which includes a nitroparaffin compound, preferably nitromethane, capable of dissolving substantial amounts of high explosive compounds, and one or more of certain high explosive compounds dissolved therein. The high explosive compounds are of a kind and are present in an amount capable of rendering the liquid explosive sufficiently diameter insensitive to permit propagation of an explosion throughout a substantial portion of such network of narrow fissures when the liquid explosive is placed therein or in such other environment as it is to be used. Preferred high explosives are RDX, HMX and mixtures thereof. TNT, PETN or any other high explosive organic nitro compound may be included in an amount sufficient to render the liquid explosive less sensitive to detonation, such that it is not cap detonable, at the same time enhancing its explosive power and reliability. For certain applications, ammonium nitrate may be added to achieve desired explosive effects, as well as finely divided reactive metal to increase the brisance of the explosive. A gelling agent such as nitrocellulose is included to maintain the resulting uniform dispersion for long periods of time. A method of pressure-transferring a liquid explosive into the well bore and pressuring it back into the productive formation is described in which the explosive is injected through a tube into the well bore directly adjacent the formation to be fractured, the tube having first been cleared of air, by placing the liquid explosive in one or more tanks connected to the injection tube at the well surface and which are subjected to air pressure to force the explosive into the well. Further, a well fracturing method which is self cleaning, rendering unnecessary the usual cleaning step which follows fracturing, is disclosed in which the well bore is restricted above the level of the explosion and is closed above the restriction with sand or the like such that sufficient back pressure is maintained in the well for satisfactory fracturing, while the resultant gases are subsequently vented through the restriction, blowing the sand or other ballast as well as the rubble generated by the explosion out of the well bore.

10 Claims, 4 Drawing Figures

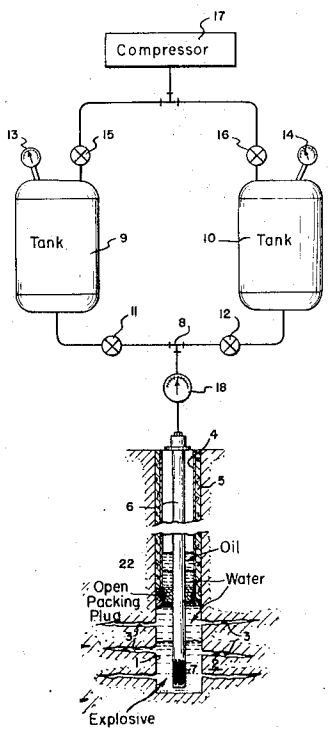


FIG. 1

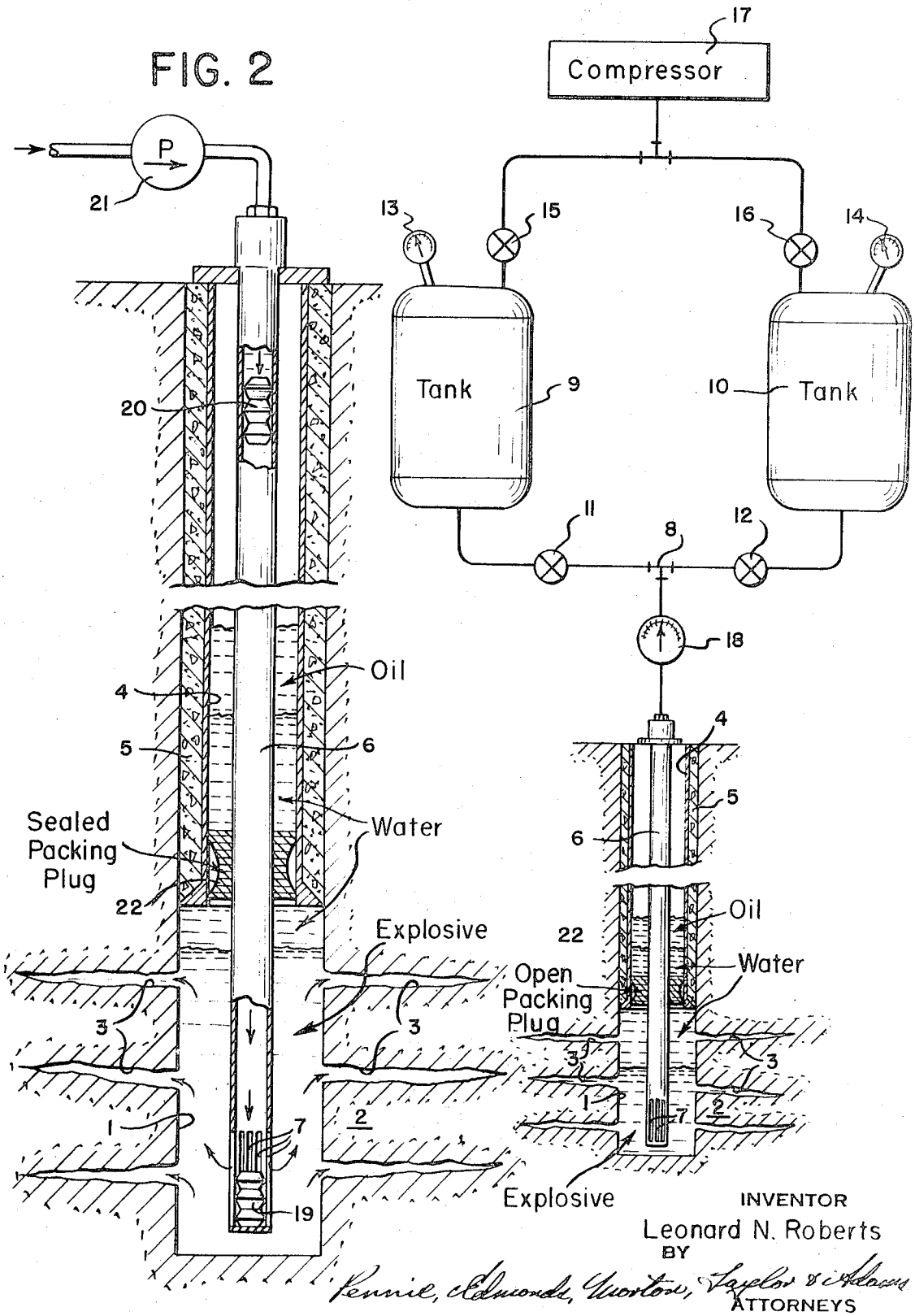


FIG. 2

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FIG. 3

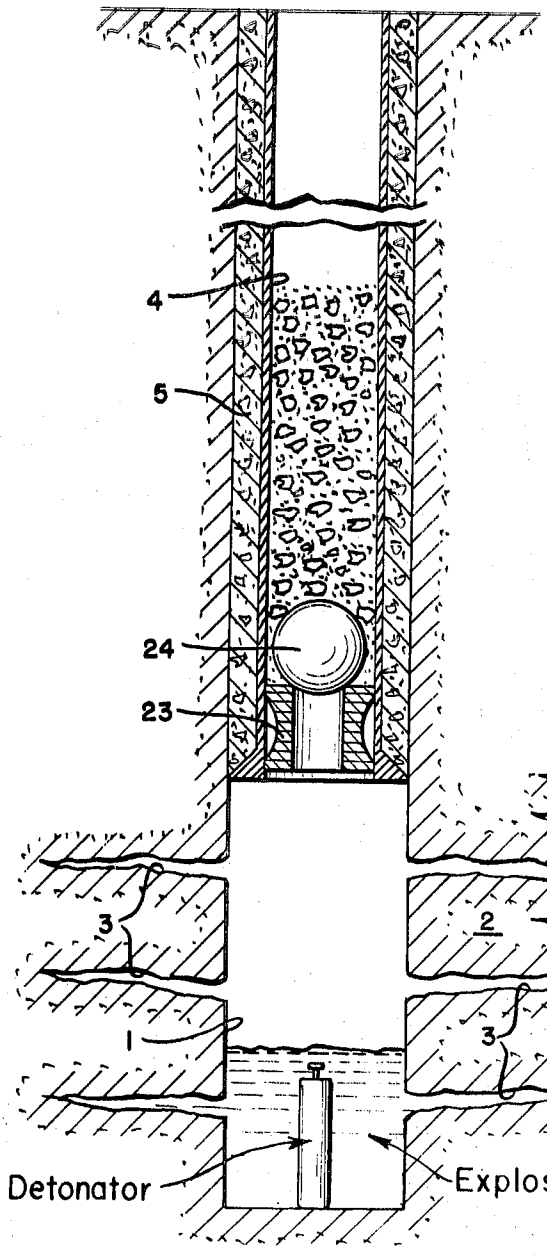
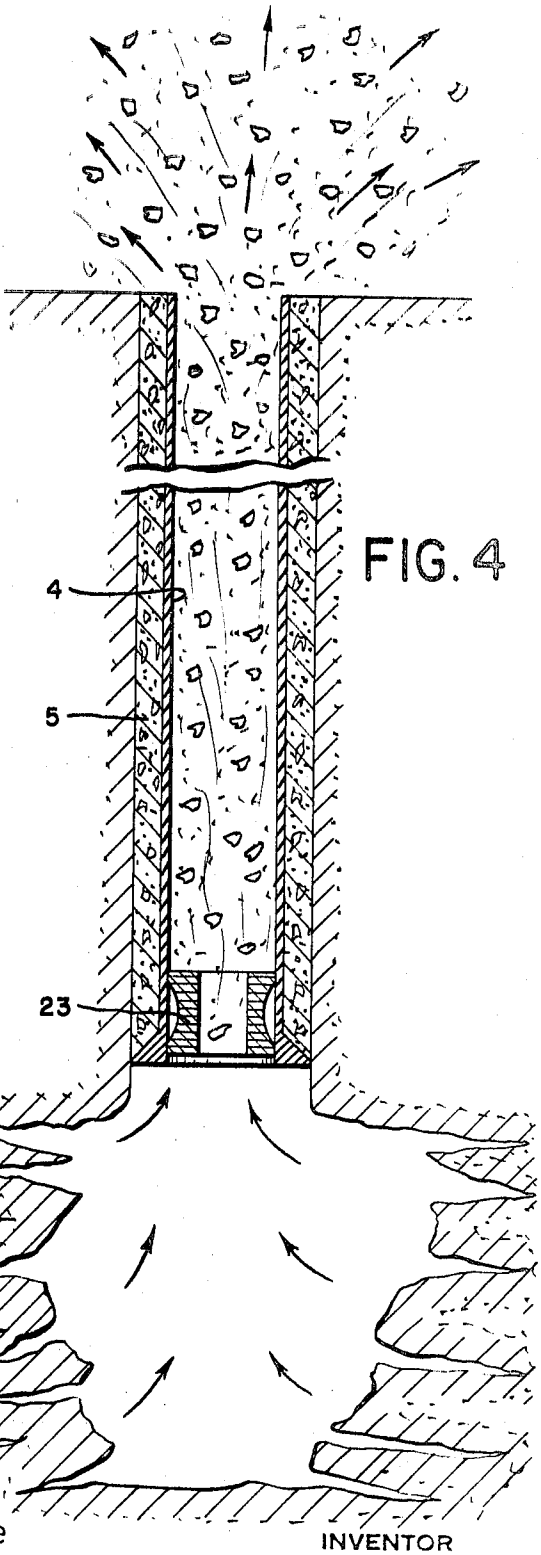


FIG. 4



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LIQUID EXPLOSIVE FOR WELL FRACTURING

CROSS REFERENCES TO RELATED APPLICATIONS

This is a continuation of my application Ser. No. 765,113, filed Oct. 4, 1968 now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a liquid explosive which is particularly suitable for fracturing a geological formation adjacent a well bore, for bringing in the well or for increasing the productivity of a well which has substantially ceased to produce oil, water or gas, and to a method of using the explosive for that purpose. The liquid explosive, particularly certain embodiments described herein, is suitable for other applications, such as quarrying, especially where an explosive composition is required which will conform to the formation in which it is placed, which is not adversely affected by oil, water or other geological fluids normally present, which has a high explosive power and which is a class B explosive, this is, it is insensitive to detonation by a No. 8 blasting cap (cap insensitive). The liquid explosive disclosed herein is especially suited to well fracturing, however, for which these properties are highly desirable, and because of its ability to propagate an explosion through a network of narrow fissures in a geological formation. The term "narrow fissures" or "fine fissures" as used herein means those fissures which may be created in geological strata adjacent well bores, commonly by hydraulic fracturing, and having widths from approximately ¼ inch down to fractions of a millimeter.

To bring in a well, after it has been drilled it is usually necessary to increase the permeability of the producing formation to stimulate flow in the well. This has commonly been done by "shooting" the well with a nitroglycerin charge, acidizing (in certain types of formations) or hydraulic fracturing. Similarly, when a formerly productive well has ceased to produce, the pay zone may be fractured to reactivate the well. The purpose of fracturing is to increase the permeability of the productive formation, or pay zone, permitting flow from the producing formation into and up the well bore.

Explosive fracturing was originally carried out by placing a nitroglycerin charge in the well bore and detonating it. The disadvantages of nitroglycerin, used for many years for this purpose, are many. For example, it is extremely shock sensitive and difficult to handle in transport; it is too sensitive, for example to be pumped or poured into a well and must be carefully placed there. Solid explosives have also been used, but cannot be made to conform to the well bore, let alone the productive formation, and consequently are of limited effectiveness. Liquid and slurry explosives other than nitroglycerin have been tried but in general have not been successful, for reasons including instability, segregation of constituents, detonation problems and vulnerability to leaching and dilution by fluids in well bores.

In explosively fracturing a well, the explosive, solid or liquid, is usually merely placed in the well bore and detonated. If no prior treatment is given the well, this results in some increase in the permeability of the formation. Because the explosive is so localized in the well bore, it is undesirably ineffective in producing an increase in permeability. Consequently, the practice has developed of initially hydraulically fracturing the productive formation in order to create a network of narrow fissures therein, so that these fissures to some extent channel the force of the subsequent explosion further back into the formation, somewhat distributing its effect. In some cases, part of the explosive is forced back under pressure into the fissures created by the hydraulic fracturing prior to detonation, obtaining a greater distribution of its effect. However, pumping explosives into wells under pressure, back into the formation, is always a hazardous procedure and special safety equipment is usually required in order to safeguard the operating personnel. Commonly, pumping and handling equipment at the surface of the well are controlled from a remote site, so that should a detonation accidentally take place, personnel will not be endangered.

In addition, when an explosive is pressured back into the formation, the resultant detonation creates large amounts of rubble and debris, necessitating an extensive cleaning operation by conventional techniques after the detonation. Some of this resultant debris, particularly the finer particles, finds its way back into the fissures and cannot be completely cleaned out, thus materially limiting the increase in permeability which can be expected with this type of fracturing.

2. History of the Prior Art

To overcome these drawbacks, experiments have been conducted for several decades with liquid explosives other than nitroglycerin and with slurry explosives, which are dispersions of solid explosives or of one or more explosive constituents suspended in water or some other medium. Liquid (including slurry) explosives have the advantage of being able to conform to and thus more readily fill the well bore, resulting in greater explosive power. It is important that explosives of this kind be capable of being pressured back into the geological formation adjacent the well bore in order to obtain complete, even and adequate fracturing of the formation and to minimize damage to the well bore and to any casing installed in the well.

A serious problem in liquid and slurry explosives developed to date has been their inability to undergo pressurization into a well formation, and still be capable of consistent and reliable detonation without the necessity of using complex and expensive detonating systems. In certain instances indispensible constituents of the explosive are filtered out in passing through the narrow fissures and pores of the formation. In other cases, exposure to fluids in the well bore or formation causes dilution of the explosive, rendering it incapable of detonation, or leaches out certain of its essential constituents.

Other explosive compositions are highly diameter sensitive, meaning that they are incapable of being detonated in spherical volumes of less than a certain diameter. Diameter sensitivity is a measure of the capability of an explosive compound to propagate an explosion in narrow passages such as geological fissures. Diameter sensitivity as used herein has reference to the ability of a composition to propagate an explosion along a tube filled with the composition, containing a restricted orifice of a given diameter, so that the explosion propagates past the orifice and is not extinguished by the reduced diameter of the composition. Thus, an explosive with a diameter sensitivity of 1 inch, placed in a tube of greater diameter will propagate an explosion past a 1 inch diameter orifice but is incapable of propagating an explosion past an orifice of lesser diameter. This indicates that the same explosive will propagate an explosion in a 1 inch diameter geological fissure.

Reference to this problem is made in U.S. Pat. No. 3,301,724, issued as recently as Jan. 31, 1967, in which it is stated:

> "A remarkable property of my inventive compositions is that they are able to propagate even in a small diameter drill hole, such as, for example, 3 inches in diameter. Many commercially used blasting compositions, such as may be produced from ammonium nitrates and diesel oil mixtures perform well in the mass and will propagate in a large diameter drill hole, such as 6 inches or larger, but fail to propagate at 3 inches or 4 inches diameter."

Clearly, however, even propagation in a 3 inch diameter hole is totally inadequate to permit effective use of such explosives for fracturing well formation. Although explosives exist which are not diameter sensitive, compositions using such explosives have encountered one or more of the other drawbacks mentioned above rendering them unsuitable for well fracturing applications. Certain of such explosives are so highly unstable as to be dangerous, while others are so insensitive to detonation in well formations that resort must be made to complex arrangements of multiple shaped charges for detonation.

As explained above, remote control for pumping and handling liquid explosives is required for purposes of safety, par-

ticularly if the explosive is to be pressured back into the formation, and such safety provisions are necessarily time consuming and expensive. While liquid explosives have been developed which are much safer than nitroglycerin, accepted safety practices generally require that they not be handled by pumps and similar conventional equipment, particularly in the presence of personnel. The reason for this is that pumps have a tendency to overheat unpredictably, resulting in a danger of accidental explosion. Consequently, there has been a need for apparatus capable of safely placing liquid explosives down into the well bore without the elaborate safety precautions currently necessary. It is not satisfactory merely to pour the explosive into the bore, for even with those explosives which, when at rest, are virtually completely impervious to fluids commonly found in well bores, dropping the explosives down through hundreds of feet of such fluids causes it to mix with the fluids, separating and churning it into globules so that the explosive is not deposited at the bottom of the bore in a continuous phase. This makes it impossible to consistently achieve detonation and propagation of an explosion throughout the explosive composition. Suggestions have been made to pump the liquid explosive directly into the well bore through a pipe leading down from the surface. However, no explosive disclosed by prior art of which the applicant is aware has been sufficiently impervious to well fluids, even after being pumped through pipes to a point adjacent the formation, to be capable of consistent and predictable detonation. Moreover, the pumping equipment used with such pipes necessitates the expensive safety precautions described above.

Another time consuming source of undue expense to the well operator is the cleaning operation, mentioned above, required after the well has been explosively fractured. Although certain of the debris settles inescapably back into the newly created fissures, thus limiting the maximum increase in productivity obtainable, a large part of this debris can be removed from the well, after it has settled, by extending conventional cleaning tools through the entire well bore and bringing them back to the surface, along with debris. Such cleaning operations are at best time consuming, and add materially to the expense of a fracturing operation.

SUMMARY OF THE INVENTION

This invention is based on the discovery that nitroparaffin compounds, which are themselves explosives but which are very diameter sensitive, may be rendered sufficiently diameter insensitive to be highly effective for well fracturing by dissolving therein certain high explosive compounds, in particular RDX, HMX and mixtures thereof. It has further been discovered that such compositions, particularly those utilizing nitromethane, which is capable of dissolving large amounts of such high explosives, are not cap sensitive when formulated in accordance with the invention and are not subject to leaching, dispersion or other forms of degradation in the well bore or formation.

An embodiment of the invention particularly suitable for well fracturing applications is a solution of nitromethane saturated with one of the high explosives mentioned above and also saturated with TNT or an equivalent high explosive organic nitro compound. Finely divided metallic powder may be added, along with a gelling agent, to enhance the brisance of the explosive.

An embodiment of the invention suitable for applications other than well fracturing is a saturated solution in a nitroparaffin compound of one of the high explosives mentioned above, along with sufficient TNT to render the composition cap insensitive as well as from about 0–50 percent finely divided ammonium nitrate. Finely divided metallic powder may also be added. A gelling agent, such as nitrocellulose, is included to maintain the constituents in stable suspension. It has been found that explosives according to the invention containing ammonium nitrate are unsuitable for use in applications requiring pressurization of the explosive through well formations containing fine fissures, since the fissures tend to filter out the ammonium nitrate, becoming clogged and preventing pressurization therethrough of the liquid explosive. However, such compositions are suitable for other applications, such as quarrying.

As previously explained, fine fissures created through hydraulic or equivalent fracturing in geological formations range generally from ¼ inch down to submillimeter levels. The diameter sensitivity required in an explosive compound for any given application depends upon the width of the fissures in which it must propagate an explosion. The width distribution of fissures in a given formation varies depending on the type of initial fracturing used to create the fissures and on the nature of the geological formation, and the diameter sensitivity of the explosive to be used should be chosen accordingly. It has been found that the explosive compound need not be capable of propagating an explosion back through all of the finest fissures in the formation, for highly effective fracturing, but should be capable of propagating an explosion through out a substantial part of the formation. It will thus be seen that, in general, the smaller the diameter sensitivity of the explosive utilized (i.e., the smaller the diameter through which it will propagate an explosion) the better the explosive will be for a given well fracturing application.

Further, in order to prevent globulation and intermixing of the explosive with well fluids, and to eliminate the need for expensive safety measures, in accordance with the present invention the liquid explosive is injected by special pressurization apparatus through an injection tube leading down from the surface to a point adjacent the formation to be fractured. The tube is connected to at least one, and preferably two or more tanks located at the surface containing the liquid explosive. The tanks are connected to the injection tube through valves, and air pressure is applied successively to the tanks in order to force their contents down through the injection tube to the formation. While one of the tanks is being emptied in this manner, the remaining one may be refilled with liquid explosive, permitting continuous loading of the explosive into the well. In this manner, the use of pumping and other equipment having a dangerous tendency to overheat is completely avoided. Further, in accordance with the present invention, a self-cleaning method for explosively fracturing a well is provided in which after the liquid explosive has been loaded into the well bore, a restrictive orifice is placed in the well bore above the level of the explosive, and the bore is loaded above the restrictive orifice with sand or rocks or the like such that, when the explosive is detonated, sufficient back pressure is maintained in the well for satisfactory fracturing, while the resultant gases are subsequently permitted to vent through the restriction blowing the sand or other ballast as well as the rubble generated by the explosion out of the well bore.

DESCRIPTION OF THE DRAWINGS

The invention will be described in conjunction with the accompanying drawings, in which

FIG. 1 is a schematic sectional view of a well bore, the upper portion of which contains a cement casing and an injection tube extending down to a potentially productive formation and connected to pressurization apparatus at the surface;

FIG. 2 is a schematic sectional view similar to FIG. 1 showing a packing plug set in the well casing and a high pressure pump connected to the injection tube;

FIG. 3 is a schematic sectional view of a well bore showing a restrictive orifice placed in the bore and covered with ballast to achieve self cleaning; and

FIG. 4 is a schematic sectional view of a well bore illustrating the self cleaning effect of the restrictive orifice shown in FIG. 3.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

1. Liquid Explosive

The liquid explosive of this invention comprises a nitroparaffin compound containing dissolved high explosives of a kind and in an amount capable of rendering the liquid explosive sufficiently diameter insensitive to permit propagation of an explosion therethrough when placed in narrow fissures (defined above) in a geological formation. Sufficient TNT or equivalent organic nitro explosive compound is preferably added to assure that the explosive is cap insensitive as well as capable of reliable detonation. Finely divided reactive metal may be added to increase the brisance of the explosive. A GELLING AGENT IS PREFERABLY included to maintain undissolved solids in a stable, even suspension. For certain applications, ammonium nitrate may be added to enhance the amounts of gas generated by the explosive.

The solvent for the liquid explosive described herein is a nitroparaffin compound, particularly nitromethane, nitroethane, notropropane, or mixtures thereof. Such nitroparaffin compounds are explosive and are not readily soluble in or desensitized by water, oil or other fluids commonly found in well bores.

According to the invention, one or more organic high explosive compounds are dissolved in the nitroparaffin compound, which are of a kind and are present in an amount capable of rendering the liquid explosive sufficiently diameter insensitive to permit propagation of an explosion through the liquid explosive when placed in the formation in which it is to be used.

Only certain high explosives are capable of diameter desensitizing nitroparaffins to render them suitable for well fracturing, including RDX (cyclotrimethylenetrinitramine) and HMX (cyclotetramethylenetetranitramine). The precise mechanism whereby particular explosive compounds render nitroparaffins diameter insensitive (and which would explain why others do not) is not known. However, laboratory experiments to date suggest that, possibly, the high explosive compounds capable of diameter desensitizing nitroparaffins are those which dissociate in solution to form ionic nitramine compounds, which compounds may sensitize the nitroparaffin in the desired manner. It may thus be the nitramine-sensitized nitroparaffin in conjunction with the explosive compound itself which produces the desired result. Consequently, it is believed that RDX, HMX, mixtures thereof and any other high explosive which forms ionic nitramine compounds with a nitroparaffin, fall within the class of high explosives suitable for use herein.

It has been found that TNT alone is incapable of diameter desensitizing the nitroparaffin solvent to render it suitable for well fracturing applications. However, TNT is preferably dissolved in the nitroparaffin solvent in addition to the RDX and/or HMX high explosive compounds in order to reduce the cost of the resultant explosive and provide more energy, as well as to render the explosive cap insensitive. Instead of (or in addition to) TNT, any high explosive organic nitro compound, for example PETN, may be used for this purpose, and when so used is referred to herein as a high explosive additive to distinguish it from the high explosive compounds described above which form nitramine compounds.

It has been found that in addition to cap desensitizing the liquid explosive, the high explosive additive increases its reliability of detonation. For applications where reliability of detonation is required, such as in well fracturing, it is important that the liquid explosive contain a high explosive additive to assure such reliability.

It is important that the nitroparaffin compound used be capable of dissolving amounts of high explosive (RDX and/or HMX) and high explosive additive capable of rendering the resultant liquid explosive reliably detonable and sufficiently diameter insensitive to permit propagation of an explosion therethrough when placed in the narrow fissures found in well formations. In this respect, nitromethane is preferred because it is capable of dissolving greater amounts of high explosive than the C_2 and C_3 nitroparaffins.

In a preferred embodiment of the invention TNT and RDX are dissolved in nitromethane making a saturated solution, so that approximately 10 percent of the TNT concentration is substituted with RDX. By thus maximizing the amounts of high explosive and high explosive additive present in the liquid explosive, the maximum diameter insensitivity is achieved as well as maximum cap desensitization, reliability of detonation and cost reduction.

From about 0–20 parts per hundred by weight of the liquid explosive may be finely divided reactive metal such as aluminum, which increases the brisance and power of the explosive. The average particle size of the metal should be below about 10 microns to minimize settling or straining out of the metal and to enhance its reactivity.

For applications not involving well fracturing, or where the explosive need not be pressured back through the formation, ammonium nitrate may be dispersed in the solvent and held in an even suspension by means of a gelling agent. From about 0–50 parts per hundred by weight ammonium nitrate may be used, depending on the particular application desired. The ammonium nitrate should be finely ground, and may be prepared by milling to an average particle size of about 10 to 20 microns in diameter. This prevents the ammonium nitrate from settling out of suspension and also permits the liquid explosive to be used in geological formations where the fissure size is not unduly small, without the suspended ammonium nitrate being filtered out of the explosive.

In order to retain in suspension all constituents of the explosive which are not in solution, such as ammonium nitrate and aluminum, a gelling agent must be added which is compatible with all constituents. A preferred gelling agent is nitrocellulose, as it is an explosive, in an amount preferably between about 1 and 3 parts by weight. Exemplary of other gelling agents which may be used with nitromethane are a cross-linked guar gum, ethyl cellulose, cellulose acetate and acetate butyrate. While no gelling agent is required for a liquid explosive containing only nitroparaffin and dissolved high explosives, it is beneficial to include a gelling agent even in such compositions to prevent settling out of any constituent which comes temporarily out of solution due to unusual temperature of similar changes. In general, the gelling agent may constitute between about 0.5 and 5 parts by weight of the liquid explosive.

One advantage of the liquid explosive compositions described above is that they are insensitive to detonation by a No. 8 blasting cap, i.e., cap insensitive. In particular, the impact sensitivity of these compositions is greater than 100 centimeters/2 Kg. weight, as tested according to U.S. Army Specification titled "Military Specification TM-9-1910," Apr. 14, 1955.

Specific embodiments of the liquid explosive prepared in accordance with the invention are illustrated in the following examples wherein all parts are by weight. The explosives may be prepared by first weighing up the ingredients in the amounts indicated below, and then adding the high explosive and high explosive additive constituents to the nitromethane or other nitroparaffin, preferably in a closed container, raising the temperature to completely dissolve the solids. Then, the nitrocellulose or other gelling agent may be added and mixed mechanically so that it is completely dissolved. Ammonium nitrate and powdered aluminum or similar metal may then be added until a homogeneous solution is achieved.

EXAMPLE I

Constituent	Parts
nitromethane	47.5
TNT	47.5
RDX	5.0

EXAMPLE II

Constituent	Parts
nitromethane	47.0

TNT	47.0
HMX	5.0
nitrocellulose	1.0

EXAMPLE III

Constituent	Parts
nitromethane	42.0
TNT	42.0
RDX	4.2
aluminum	9.8
nitrocellulose	2.0

EXAMPLE IV

Constituent	Parts
nitromethane	25.4
PETN	25.4
RDX	2.5
nitrocellulose	1.7
ammonium nitrate	40.0
aluminum	5.0

EXAMPLE V

Constituent	Parts
nitropropane	50.0
TNT	23.0
RDX	2.0
ammonium nitrate	22.0
cellulose acetate	3.0

2. Loading the Explosive into a Well

An advantage of the liquid explosive composition described herein is that the nitromethane or other nitroparaffin solvent renders the composition substantially impervious to well bore fluids such as crude oils, water and acids, which adversely affect most other liquid explosives containing ammonium nitrate. However, as stated above, it is believed in falling down a well bore through hundreds of feet of water and other fluids, liquid explosives become intermixed with the bore fluids, forming globules, so that a continuous phase of explosive is not formed in the bore. It is believed that this may be one cause of detonation failure or unreliability in previous unsuccessful attempts at fracturing wells in this manner.

Consequently, in accordance with this invention, the liquid explosive is injected into the formation through an injection tube to a point adjacent the formation to be fractured, preventing it from contacting and intermixing with well fluids on the way down into the bore hole. This method is partially described in copending U.S. application Ser. No. 716,056, now U.S. Pat. No. 3,561,532 filed Mar. 26, 1968 by Dr. David A. Fletcher and myself and directed to a Well Fracturing Method and Explosive Slurry for Use Therein. Preferably, the injection tube is constructed so as to permit forcing the air or fluids out of it before sending the explosive through it, preventing them from interfering with the formation of a continuous phase of high explosive in the well bore.

FIG. 1 shows a well bore 1 extending into a productive formation 2 containing fissures 3 formed by hydraulic fracturing or the like. Such fissures exist in most wells from the initial fracture used to bring in the well; they may be enlarged by refracturing prior to the explosive fracture.

The upper portion of the well bore is provided wit a casing 4 lined with concrete 5. An injection tube 6 extends down through the well bore to the productive formation, which is closed at its lower end and provided with slots 7 about its lower end portion through which explosive may flow into the well bore.

The upper end of the injection tube, which may conveniently be formed of pipe having an inner diameter of 2 inches, is connected through a T-fitting 8 to two pressure tanks 9 and 10 through respective valves 11 and 12. Each pressure tank is provided with an air pressure gauge 13, 14 and an air inlet valve 15, 16 through which it is connected to an air compressor 17. A flowmeter 18 is connected in the injection tube to measure the quantity of explosive passing through it.

Pressure is required for loading the explosive into the well in order to overcome the bottom pressure of the well. To load the explosive, one of the tanks 9, 10 is filled (through a fill cap, not shown) with explosive and pressurized by the compressor to force its contents through the injection tube into the well. In order to purge the injection tube of air or fluids which might otherwise mix with the explosive, a wiper plug 19 is first inserted into the injection tube, at any convenient coupling, and is then forced down through the tube by the pressure above it of the liquid explosive. When the wiper plug reaches the bottom of the injection tube it is trapped against the bottom of the tube leaving slots 7 sufficiently exposed to the flowing explosive so that it flows freely into the well bore.

While one tank is emptying under pressure into the well, the other may be filled so that it may be pressurized and connected to communicate with the injection tube through the appropriate valves when the first tank is empty or, preferably, nearly empty, as indicated by the flowmeter.

In this manner, a continuous flow of explosive under pressure into the well bore is achieved, without interruption and without subjecting the explosive to heat and pressure from mechanical pumps which constitute an explosion hazard.

If it is desired to pressurize the explosive back into the formation then after a sufficient amount of explosive has been placed in the well bore, including that remaining in the injection tube, a second wiper plug 20 is placed in the top of the injection tube and the latter is disconnected from the pressurization tanks and connected to a high pressure (up to about 2,000 psi) pump 21. Water is then pumped in under high pressure, filling the injection tube and displacing the liquid explosive ahead of the second wiper plug 20 back into the formation, as shown in FIG. 2.

Before pressurizing the explosive in this manner, however, a packing plug 22 is placed in the well bore above the production formation, preferably at the lower end of the well casing. Such packing plug 22 may be placed in the well when the injection tube is first lowered into it and may be left open at that time in order to permit air or fluids in the well bore to be displaced upward past the packing plug when explosive is loaded into it, as in FIG. 1. Packing plug 22 is preferably of a type which is sealable by rotation of the injection tube, with which it is interlocked in a known manner. Thus, before pressurizing the explosive into the formation, the well bore can be closed off by sealing the packing plug 22 so that pressure built up by the high pressure pump 21 will force the explosive back into the formation.

When the second wiper plug 20 reaches the bottom of the injection tube, the top is sealed off from communication with the well bore, since the lengths of the first and second wiper plugs are made so that their sum is greater than the height of the slots 7. By this means, water is prevented from entering the well bore and churning up the explosive. After all the liquid explosive has been placed in the well, pressure is maintained until the internal wall pressures have reached equilibrium (about ½ hour), thus preventing regurgitation from the formation of the explosive when pressure from above is relieved. Subsequently, the injection tube and pumping apparatus are removed from the well and the bore is filled with water or other shock absorbing fluid to a height at least sufficient to balance any back pressure from the well. A suitable high explosive booster charge is then lowered down the well bore such that it is completely surrounded by liquid explosive. The booster may contain any conventional explosive such as Composition B or nitroglycerin commonly used for this purpose, and the detonator may conveniently include a timer for effecting detonation automatically after a predetermined interval of say, several hours.

Note that the gelling agent present in the explosive must be capable of maintaining an even dispersion of its constituents under conditions of temperature (up to about 150° F.) and pressure (up to about 5,000 psi) encountered in well fracturing. Finally, a packing plug is seated above the water which has been placed in the e bore, and the well is further filled with water; after detonation the packing plug is removed and the well cleaned using conventional techniques.

3. Self Cleaning Explosive Fracturing Method

In accordance with the invention, in order to preclude having to clean the well bore as described immediately above, and in order to avoid having rubble from the explosion fall back into the fissures created thereby, unduly limiting the effectiveness of fracturing, a method is provided for rendering the explosive fracture self cleaning. To this end, instead of sealing the well before detonation or using a conventional packing plug, a packing plug **23** is seated in the well bore as shown in FIG. **3**, above the fluid column, which contains about a 3 inch orifice from top to bottom, thereby creating a restriction in the well bore. By adjusting the height of the fluid column below the packing plug, an approximate pressure equilibrium may be maintained within the well. Then, a spherical plug **24** having a diameter less than that of the well bore but substantially larger than that of the orifice in packing plug **23** is placed above the packing plug, and the space above it filled with sand and rock or any other ballast.

The spherical plug **24** acts as a one-way valve, preventing the ballast from falling into the well but permitting pressure from within the well to be relieved upwardly through it. Sufficient ballast should be placed above plug **23** to create pressure within the well adequate to achieve the desired fracturing, yet permitting gases created by the explosion to blow the ballast, the plug and virtually all of the rubble created by the explosion up out of the well bore. Usually several hundred pounds of ballast suffices for this purpose.

FIG. **4** illustrates the self cleaning effect achieved. Within about 15 or 20 seconds of the detonation, during which time the shock wave of the explosion fractures the formation, sufficient pressure is developed to blow anything within the well bore out above the surface in a geyser, as shown. The packing plug **23** may sometimes be blown out of the bore hole by this explosion.

In accordance with the invention it is desirable to place the maximum amount of liquid explosive possible back into the formation, at the same time leaving sufficient explosive in the well bore to assure reliable detonation and propagation of the explosion. In this manner, the explosive is distributed substantially spherically through the formation rather than being concentrated in a pool at the bottom of the well bore, thereby optimizing the efficiency of the explosion in fracturing the formation.

The following are examples of a method disclosed herein of fracturing well formations using one of the liquid explosive compositions described in the foregoing examples, as well as examples of self cleaning explosive fracturing. While no information exists with respect to the exact value of diameter sensitivity required to obtain effective fracturing in any given well, excellent results have been obtained generally utilizing an explosive having a diameter sensitivity of approximately 1/32 inch.

EXAMPLE VI

A well having a productive formation at a depth of about 2,400 feet and which had substantially ceased to produce was cleaned using a conventional technique to remove paraffins and the like. A liquid explosive having the composition described in example II above was then placed in pressure tanks connected to an injection tube which extended down to the productive formation, as shown in FIG. 1. A wiper plug was placed in the injection tube ahead of the explosive, and approximately 4,000 pounds of explosive were placed in the well bore. A second wiper plug was then inserted and the injection tube reconnected to a high pressure pump which forced water under pressure through the injection tube, thereby forcing the explosive back into the formation. Before the high pressure pump was turned on, a packing plug previously placed at the bottom of the well casing (which extended down about 1,000 feet from the surface) was sealed to permit pressure to be built up by the pump. After approximately 85 percent of the explosive had been pressured back into the formation, as determined by monitoring the amounts of water and explosive through the flowmeter, pressure was maintained for 15 minutes, after which the injection tube and pumping equipment were removed from the well. A detonator timed for 3 hours and containing a charge of Composition B was then placed wholly within the liquid explosive remaining in the well bore as determined by sensing the level of the explosive with a thermal probe. The well bore was filled to the bottom of the well casing with water and a packing plug was seated at that height, after which several hundred feet more of water were loaded into the bore over the packing plug. After detonation, the packing plug was removed and resultant debris cleaned out of the well by conventional techniques. Initial tests indicated about a ten fold increase in productivity.

EXAMPLE VII

The method of example VI was carried out using 6,000 pounds of the liquid explosive of example III. About 80 percent of the explosive was pressured back into the formation. Instead of sealing the well bore with a solid packing plug, a packing plug having 3 inch diameter hole was seated about 100 feet above the bottom of the well casing, which extended down 1,500 feet from the surface. The depth of the well was 4,000 feet. Water was then placed in the well up to the annular packing plug. This column of water substantially equalized the bottom pressure in the well.

A 9 inch diameter rubber ball was placed over the hole in the packing plug, and approximately 600 pounds of mixed sand and rock were loaded in above it. About 15 seconds after the shock wave from the detonation was first felt, a geyser of debris appeared above the surface of the well, which lasted for close to 30 seconds. Without cleaning, productivity rose from 1 barrel per day (before fracturing) to 40 barrels per day.

It will be appreciated by those skilled in the art that the exemplary embodiments described above may be modified and still remain within the scope and spirit of the invention, which is limited solely in accordance with the following claims.

I claim:

1. A method of safely pressure-transferring a liquid explosive into a well bore for explosively fracturing the productive strata of the well, such that the liquid explosive is not subject to the possibility of accidental detonation by contact with pumps and similar machinery, comprising placing the liquid explosive in a tank located at the surface and connected to communicate directly with the well bore thorough an injection tube which extends down into the well bore, terminating at a point adjacent the formation to be fractured so as to prevent globulation and mixing of the explosive with well fluids in the bore; and applying pressure over the liquid explosive within the tank greater than the pressure exerted by the well tending to force explosive upward into said tank by an amount sufficient to force the liquid explosive through the injection tube into the well bore.

2. A method of safely pressure-transferring a liquid explosive into a well bore for explosively fracturing the productive strata of the well, such that the liquid explosive is not subject to the possibility of accidental detonation by contact with pumps and similar machinery, comprising placing the liquid explosive in a tank located at the surface and connected to communicate directly with the well bore through an injection tube which extends down into the well bore terminating at a point adjacent the formation to be fractured so as to prevent globulation and mixing of the explosive with well fluids in the bore; and applying pressure over the liquid explosive within the tank greater than the pressure exerted by the well tending

to force explosive upward into said tank by an amount sufficient to force the liquid explosive through the injection tube into the well bore; said method including the provision of a second tank connected to the injection tube and the provision of valves between each tank and the injection tube, including filling the second tank with liquid explosive while the first tank is being emptied of its contents, and then disconnecting the first tank from the injection tube and connecting the second tank to the injection tube by their respective valves and applying pressure over the liquid explosive in the second tank to force it down through the injection tube into the well bore, while refilling the first tank with liquid explosive.

3. A method as defined in claim 2 wherein the outlet end of the injection tube is closed, the sides of the tube adjacent said end being provided with slits permitting outflow from the injection tube of liquid explosive, including placing a wiper plug having a length substantially less than the length of said slits in the injection tube before injecting liquid explosive therethrough in order to prevent mixing between air or well fluids and the liquid explosive.

4. A method as defined in claim 3 for pressurizing the liquid explosive back into the productive strata, which strata have been hydraulically or similarly fractured to create a network of fine fissures therein, including after the liquid explosive has been pressure-transferred into the well bore,

disconnecting said tanks from the injection tube;

inserting into the injection tube a second wiper plug such that the combined lengths of the first and second wiper plugs are greater than the length of the slits at the outlet end of the injection tube;

seating a packing plug in the well bore above the productive strata in order to seal off the well bore; and

pumping water into the injection tube under pressure sufficient to force the liquid explosive through the injection tube and back into the fissures in the productive strata.

5. A method as defined in claim 4 including removing said packing plug, after the pressures within the well bore have substantially attained equilibrium;

placing a timed explosive detonator within the liquid explosive remaining in the well bore; and

sealing the well bore by seating a packing plug therein and filling the bore with water above and below the packing plug.

6. A self cleaning method for explosively fracturing a well as defined in claim 4, comprising filling the well bore above the liquid explosive with enough water to substantially counterbalance the bottom pressure existing in the well;

placing a restriction in the well bore above the level of said water;

sealing said restriction from above in order to prevent matter from falling down therethrough; and

loading ballast into the well bore above the restriction, the amount of ballast and the size of the restriction being such as to create sufficient pressure within the well bore, upon detonation, to achieve the desired fracturing while permitting gases generated by the explosion to blow the rubble created thereby as well as the ballast up and out of the well bore.

7. A self cleaning method of explosively fracturing a well in order to bring in the well or to increase its productivity, the productive strata of said well having been hydraulically or similarly fractured in order to create a network of fine fissures therein, comprising:

loading liquid explosive into the well bore and pressuring a portion thereof back into the productive strata;

placing an explosive detonator within the liquid explosive remaining in the well bore;

filling the well bore above the liquid explosive with water in an amount sufficient to balance the bottom pressure of the well;

placing a restriction in the well bore above the level of said water;

placing a seal above said restriction in order to prevent material from falling down therethrough; and

loading ballast into the well bore above the restriction, the size of the restriction and the amount of ballast being such that, upon detonation, sufficient pressure is developed within the productive strata to achieve the desired fracturing, yet the gases generated by the explosion are capable of forcing the rubble created thereby as well as the ballast up and out of the well bore.

8. Apparatus for pressure-transferring liquid explosive into a well bore to fracture the productive strata thereof, comprising:

an injection tube extending down into the well bore to the level of the productive strata;

at least two pressure tanks at the surface of the well, each pressure tank being connected through a valve to the injection tube; and

means including an air pressure source connectable to each pressure tank for selectively placing said source in communication with each tank to force liquid explosive placed therein through the injection tube into the productive strata.

9. Apparatus as defined in claim 8, said injection tube being closed at its lower end and having slots in its periphery about said lower end to permit flow therethrough of liquid explosive, said slits being sufficiently long to permit flow of liquid explosive after a wiper plug has been lodged in the lower end of the injection tube.

10. A self-cleaning method of explosively fracturing a well in order to bring in the well or to increase its productivity, the productive strata of said well having been hydraulically or similarly fractured in order to create a network of fine fissures therein, comprising:

loading liquid explosive into the well bore and pressuring a portion thereof back into the productive strata;

placing an explosive detonator within the liquid explosive remaining in the well bore;

filling the well bore above the liquid explosive with fluid; and

placing a tamp in the well bore above the level of the liquid explosive, which tamp includes a supporting bridge in the well bore and ballast supported thereon, said bridge and ballast being such as to create sufficient pressure within the productive strata, upon detonation, to achieve the desired fracturing while permitting gases generated by the explosion to blow the rubble created thereby as well as the ballast up and out of the well bore.

* * * * *

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,659,652 Dated May 2, 1972

Inventor(s) Leonard N. Roberts

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

Abstract, line 3 not printed, should read --in order to bring --

Column 2, line 66, reads "well formation", should read --well formations--

Column 6, line 40 reads "of similar", should read --or similar--

Column 7, line 68 "wit" should read --with--

Column 8, line 62 "internal wall" should read --internal well--.

Column 9, line 6 "the e bore" should read --the bore--

Column 10, line 54 "thorough" should read --through--.

Signed and sealed this 2nd day of January 1973.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents