

[72] Inventors **David A. Fletcher**
Mesa;
Leonard N. Roberts, Scottsdale, Ariz.
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[73] Assignee **Talley-Frac Corporation**
Pryor, Okla.
a corporation of Delaware

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Primary Examiner—Ian A. Calvert
Attorney—Pennie, Edmonds, Morton, Taylor and Adams

[54] **WELL FRACTURING METHOD USING
EXPLOSIVE SLURRY**
8 Claims, 4 Drawing Figs.

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149/92, 149/93
[51] Int. Cl..... **E21b 43/26**
[50] Field of Search..... **166/36,**
42.1, 153, 156, 299; 102/22, 23; 86/20.3 (Inquired);
149/2, 92, 93 (Inquired)

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ABSTRACT: A method of fracturing a geological formation adjacent a well bore is described, comprising injecting a free-flowing explosive slurry, which is nondispersible in well fluids over a time period required to fracture the formation and thus retains its initial density until fracturing and which contains a granular explosive which is nonhygroscopic and insoluble in the dispersive medium of the slurry, into the well bore directly adjacent the formation to be fractured, so that the slurry cannot contact fluids in the well bore before reaching the formation, then placing a detonating device in the slurry and detonating it to explode the slurry. The explosive slurry used in the method is an even dispersion in an inert fluid dispersive medium of a granular solid explosive, which is an organic nitro compound of high explosive power and which is insoluble in the dispersive medium, to which is added a gelling agent for maintaining the solid explosive evenly dispersed throughout the fluid medium under conditions of temperature and pressure encountered in well fracturing.

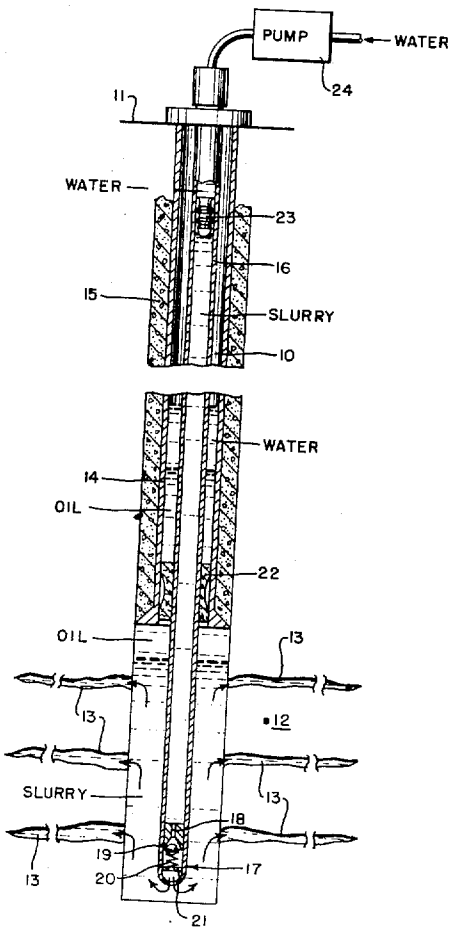


FIG. 1

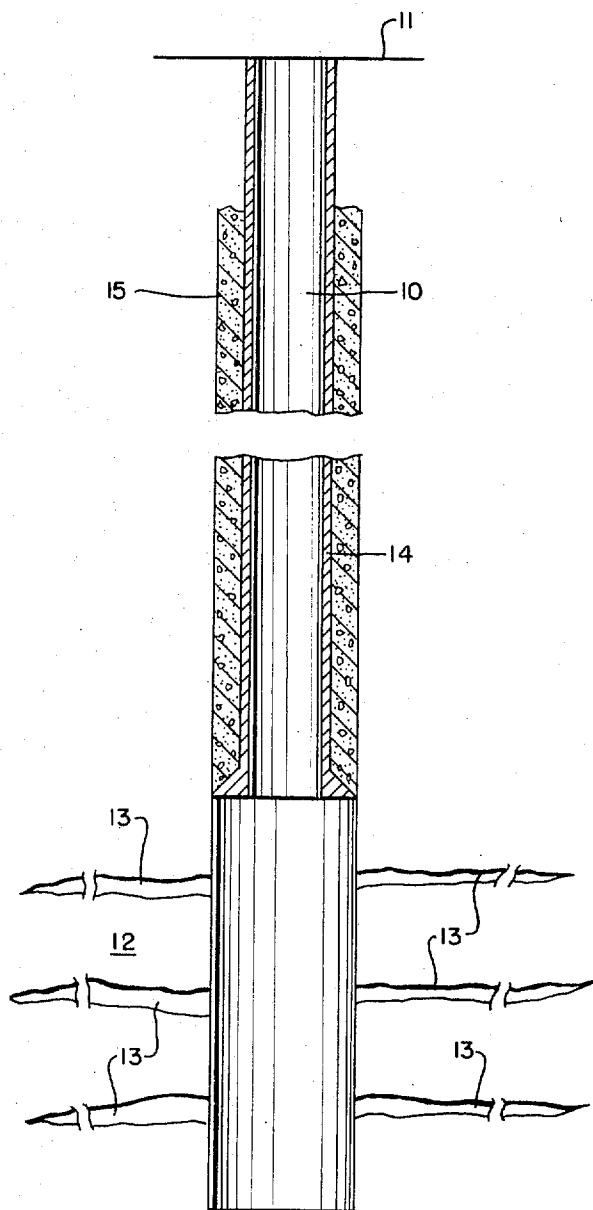
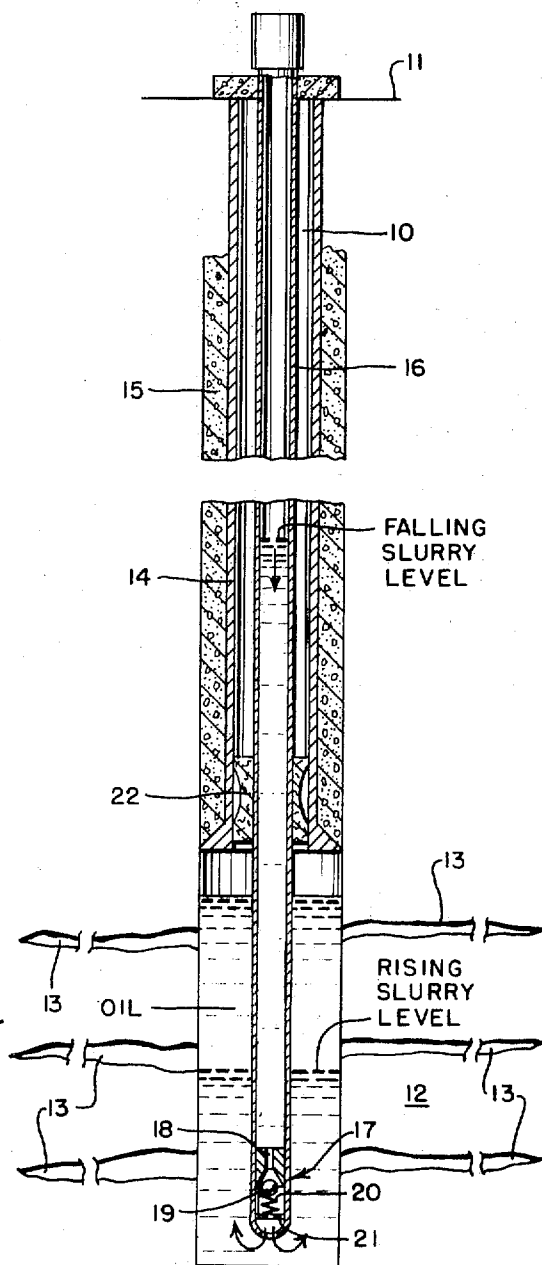


FIG. 2



INVENTORS

DAVID A. FLETCHER
LEONARD N. ROBERTS

BY *Pennie, Edmonds, Morton,
Taylor & Adams*

ATTORNEYS

FIG. 3

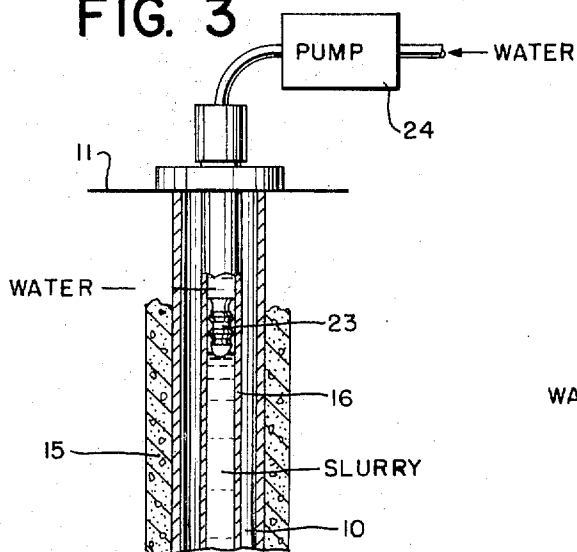
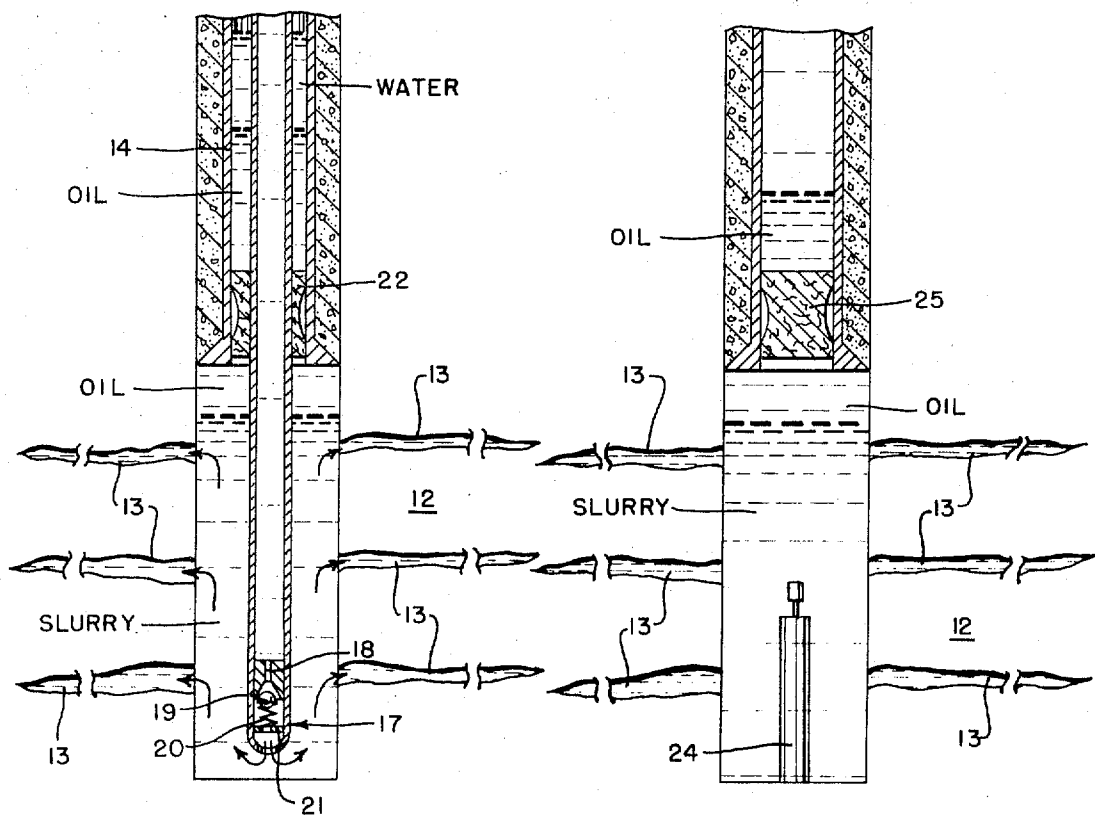
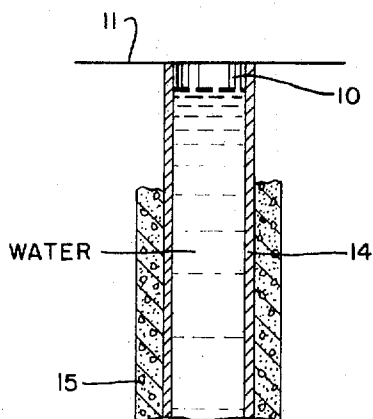


FIG. 4



INVENTORS

DAVID A. FLETCHER
LEONARD N. ROBERTS

BY *Pennie, Edmonds, Morton,
Taylor & Adams*
ATTORNEYS

WELL FRACTURING METHOD USING EXPLOSIVE SLURRY

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to well fracturing, particularly the explosive fracturing of a geological formation adjacent a well bore, for bringing the well in or for increasing the productivity of a well which has substantially ceased to produce oil, water or gas. While the explosive slurry herein described is useful for other applications, such as mining, the present application is concerned with its use in well fracturing. To bring in a well, after it has been drilled, it is usually necessary to increase the porosity of the producing formation, or pay zone, to stimulate flow in the well. This has commonly been done by "shooting" the well with a nitroglycerine or TNT charge; acidizing, in certain types of formations; or hydraulic fracturing. Similarly, when the pay zone of a formerly productive well has ceased to produce, hydraulic or explosive fracturing of the pay zone is used to bring the well back into production. The purpose of fracturing is to increase the porosity of the productive formation, permitting oil (water or gas) to flow into and up the well bore.

Explosive fracturing was originally carried out by placing a nitroglycerine charge in the well bore and detonating it. While liquid nitroglycerin has been used for this purpose for many years, it is extremely shock sensitive and difficult to handle and 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 they are difficult to get into the well bore and cannot be made to fill the bore, let alone the productive formation, and consequently are of limited effectiveness in increasing the porosity of the formation.

Liquid explosives other than nitroglycerine have also been tried but in general have not been successful because of the instability of the explosives or explosive mixtures used.

2. History of the Prior Art

To overcome these drawbacks, experiments have been conducted since the early 1950's with slurry explosives, which are dispersions of solid explosives or of one or more constituents which together constitute an explosive, suspended in water or some other dispersive medium. Slurry explosives have the advantage of being able to conform to and thus more readily fill the bore hole, resulting in greater explosive power. Fracturing may be enhanced, moreover, by pumping the slurry under pressure directly into the formation to be fractured, thereby improving the effectiveness of the charge in increasing porosity. However, to the inventors' knowledge, no commercially successful slurry explosive for well fracturing has yet been produced; they have been for the most part either too unstable, leading not infrequently to accidents in the field or, more often, have been incapable of consistent and predictable detonation.

The bulk of slurries developed to date, many of which include gelling agents, have used ammonium nitrate as a major constituent. Such slurries are generally unpredictable in their detonation characteristics, and often will not detonate at all. One reason for this is believed to be that ammonium nitrate is relatively hygroscopic and water soluble. When exposed to fluids commonly found in the well bore, the slurry is sufficiently diluted to render it nondetonatable. Some attempts have been made to overcome this difficulty by using shaped charges for detonation, but even this has not proven entirely successful. Further, shaped charges are relatively difficult to use, and are therefore undesirable.

One proposed method which appears to have avoided at least this drawback involved sealing slurry in polyethylene bags, and placing the sealed bags in the bottom of the well bore adjacent the formation to be fractured, to prevent the slurry contained in the bags from being diluted before detonation. However, aside from the relative difficulty of placing the

bags in the well bore, substantially less explosive force can be developed at the formation with this method than with an unconfined slurry such as is used in the present invention. Some work has also been done with propellant type (as opposed to explosive type) liquids and slurries; however, these have to a large extent proved unstable and thus are not suited for commercial application.

Some of the slurries developed to date are dispersions of granular solid explosives in water or hydrocarbons; however, tests of such slurries have been largely unsuccessful, principally due to detonation difficulties, even though a booster charge is used. The difficulty encountered in detonating such slurries is exemplified by U.S. Pat. No. 2,867,172 to Hradel, which points out the necessity for extensive safety precautions in using conventional detonators, which had to be intimately mixed with the basic explosive in the bore hole, and in particular the difficulty of achieving detonation where the slurry was to be pressurized into the formation. As a solution, Hradel proposed that a complicated arrangement of shaped charges be set in the bore hole to detonate the slurry, which in particular was a dispersion of RDX, Composition B, ammonium nitrate or similar materials in a dispersive medium such as water. The patent states that the particles of explosive in the slurry are trapped in fissures in the formation, forming a continuous phase of explosive material which may then be detonated by the arrangement of multiple shaped charges (see FIG. 2). Assuming that this procedure works, it is commercially highly unsatisfactory due to the necessity of the complex shaped charge detonation procedure. The patent appears to recognize, moreover, that the explosive constituents were capable of dissolving in the dispersive medium, or of settling out (col. 3), which may have been, at least in part, the reason why the multiple shaped charge detonation procedure was thought to be required.

SUMMARY OF THE INVENTION

This invention is based on the discovery that by providing a slurry explosive which is nondispersible in well fluids over a time period required to fracture the formation and thus retains its initial density until fracturing and which contains a granular explosive which is nonhygroscopic and insoluble in the dispersive medium of the slurry, and by injecting such slurry explosive into the well bore directly adjacent the formation it is desired to fracture, so that the slurry cannot contact oil or water in the well bore (and thus be emulsified, leached out or otherwise diluted) before reaching the formation, it is possible to fracture a well with complete safety, at the same time achieving consistent and reliable detonation.

Preferably, the slurry is injected into the well bore directly adjacent the formation to be fractured by pouring it through a tube extending from the surface down through the well bore to the formation, which tube is provided at its lower end with a one-way valve for permitting flow from the tube into the well bore while preventing flow in the reverse direction. The slurry is thus placed in the well directly at the formation, precluding any chance of its being diluted or otherwise adversely affected by well fluids on the way down the well bore.

The slurry used in this method must be nondispersible in well fluids over a time period (usually at least a few hours) required to fracture the formation, so that it retains its initial density until fracturing, and contains a granular solid explosive which is nonhygroscopic and insoluble in the dispersive medium of the slurry. It comprises an inert fluid dispersive medium, one or more granular solid explosives which are organic nitro compounds of high explosive power and which are insoluble in the dispersive medium, and a gelling agent for maintaining the granular solid explosive evenly dispersed throughout the dispersive medium under conditions of pressure and temperature existing in well fracturing.

Preferably, the slurry is composed of a dispersive medium such as water, kerosene or alcohol having dispersed therein, in granular form, RDX, PETN, HMX, TNT or a mixture of the

foregoing, as well as a gelling agent compatible with the particular dispersive medium and explosive and capable of maintaining an even dispersion of the latter under conditions of temperature and pressure existing in well fracturing.

In a particular preferred embodiment of the invention, the slurry is a dispersion of about between 45 percent and 70 percent RDX in water, with about 0.5 percent Carbopol 941, a gelling agent.

BRIEF DESCRIPTION OF THE DRAWINGS

Particular embodiments of 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 which extends into a potentially productive formation;

FIG. 2 is a schematic sectional view showing a tube in the well bore of FIG. 1 extending into the formation;

FIG. 3 shows the well bore of FIGS. 1 and 2 with a pump connected to the tube for pressurizing slurry into the formation; and

FIG. 4 shows the well bore of FIGS. 1—3 with a packing plug seated at the lower end of the casing above the formation.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Explosive Slurry

The explosive slurry, according to the invention, is composed of a dispersive medium, a granular solid explosive evenly dispersed therein, and a gelling agent for maintaining an even dispersion of the explosive throughout the dispersive medium.

The dispersive medium may be water, or any of a number of suitable hydrocarbons or hydrocarbon derivatives such as hexane, kerosene, or denatured alcohol. It must be inert, and capable of desensitizing the granular explosive, and must be of sufficient density so that the slurry is substantially more dense than fluids which may be encountered in the well bore. Water in particular is an excellent and inexpensive desensitizing agent. This assures that the slurry will settle on the bottom of the well bore, causing any other fluids present to rise above it. The dispersive medium must also be compatible with the particular explosive and the particular gelling agent used; will be chosen to be compatible with the dispersive medium and explosive.

The granular solid explosive may be any one or more organic nitro compounds of high explosive power, preferably about equal to or greater than that of TNT. It is essential that the explosive be insoluble in the dispersive medium and that it be nonhygroscopic. While most organic nitro compounds are to a minor extent soluble in the dispersive media mentioned above, as used herein the expressions "insoluble" and "nonhygroscopic" are intended to mean that the explosives described are essentially insoluble or nonhygroscopic, and consequently are detonatable.

Preferred organic nitro compounds include RDX (cyclotrimethylene trinitramine), HMX (cyclotetramethylene tetranitramine), and PETN (pentaerythritol tetranitrate). TNT may also be used. To assure that the suspended particles of explosive are able to pass into and through fissures in the formation, the explosive should have a grain size which is preferably below about 100 mesh, for example, 200 microns.

The gelling agent must be capable of maintaining an even dispersion of the granular explosive under conditions of temperature (up to about 150° F.) and pressure (up to about 5,000 p.s.i.) encountered in well fracturing, must render the slurry nondispersible in well fluids over a time period required to fracture the formation, so that it retains its initial density until fracturing, and must be compatible with the particular explosive and dispersive agent used. The gelling agent or dispersing agent may be any one of such agents manufactured under the trademark "Carbopol" (a trademark of B. F. Goodrich Chemical Company, New York for carboxy vinyl polymers of extremely high molecular weight which are water

soluble and supplied in acid form for use as thickening, dispersing, suspending and emulsifying agents) or any one of the fatty acid or protein colloid gelling agents. It may be a protein-based gel, an aluminum silicate or any one of the metallo-organic compounds suitable for this purpose. Generally the gelling agent will constitute between about 0.5 and 3 percent by weight of the slurry.

The proportions of granular explosive and dispersive medium used will depend upon the particular conditions involved. However, sufficient explosive must be present to achieve detonation, whereas if too much explosive is present, the slurry will not be free-flowing and will be too viscous to pump or pour. Further, settling tends to occur in less viscous slurries unless a higher proportion of gelling agent is present. In an RDX-water system, RDX should constitute about between 45 and 70 percent by weight of the slurry. Within this range, the material is detonatable and free flowing; below this range the slurry is insensitive to detonation and above this it is too viscous.

In an RDX-kerosene or RDX-denatured alcohol slurry, the RDX may constitute between about 35—70 percent by weight of slurry. Preferably, the explosive constitutes about between 55 and 65 percent by weight of slurry. The slurry may be prepared in any of a number of ways; a preferred method, for example in an RDX-water slurry, is to weight up the dispersive medium, granular explosive and gelling agent in the desired proportions. A dual-impeller mixer is placed in the dispersive medium so that a vortex is formed and the gelling agent is slowly added into the vortex. The mixer shaft is then repositioned to eliminate the vortex and mixing is continued until a thin hazy dispersion is achieved. Assuming that the gelling agent in this case is Carbopol 941 or a similar agent which is commercially available in acid form, a base such as 10 percent sodium hydroxide solution is then added until the pH reaches between 5 and 7, at which point a gel immediately forms. The granular explosive is then added, continuing agitation until a complete and even dispersion is obtained.

Specific embodiments of free-flowing explosive slurries according to the invention are illustrated in the following examples, wherein all parts are by weight.

EXAMPLE I

	Parts
RDX.....	48
Water.....	51.5
Carbopol 941.....	0.5

EXAMPLE II

	Parts
HMX.....	60
Water.....	39
Hydrated silica dispersing agent (Cab-O-Sil).....	1

EXAMPLE III

	Parts
RDX.....	49
Ethyl alcohol (denatured).....	49
Carbopol 941.....	2

EXAMPLE IV

	Parts
PETN.....	50
Water.....	49
Carbopol 941.....	1

In a nonaqueous slurry, finely powdered metals may be added to enhance the explosive power of the slurry.

2. Well Fracturing Method

The well fracturing method according to the invention comprises injecting a slurry explosive such as is described above into the well bore directly adjacent the formation to be fractured such that the slurry cannot contact fluids in the well

bore before reaching the formation, placing a detonating device containing a high explosive charge within the slurry in the well bore, and detonating the explosive charge.

It is essential in well fracturing by this method that the slurry be nondispersible in well fluids over a time period required to fracture the formation (i.e., the time during which the slurry is in contact with well fluids), so that it retains its initial density until fracturing, and that the slurry be injected into the well directly adjacent the formation to be fractured. While dilution of the solid explosive in the dispersive medium is necessary to desensitize it, and thereby to render its use safe, maintenance of the concentration of the explosive is essential to proper detonation. If the explosive is diluted by well fluids, such as water (which may for example be somewhat acidic), or settles out, detonation will not occur. An even dispersion is necessary because the detonating device carrying the high explosive charge must be surrounded by the slurry in order to detonate it.

Thus, in certain instances in which the slurry has been poured directly into the well bore (as opposed to being injected through a tube to the formation), well fluids have leached sufficient gelling agent out of the slurry to cause settling out of the explosive and, consequently, detonation failure. Detonation failure may also occur, even though direct injection is used, if the slurry is dispersible in fluids in the well bore at the formation in a time period less than that required for fracturing by this method. Detonation failure can be consistently avoided under all conditions only by using the slurry and method described herein.

As shown in FIG. 1, a well bore 10 extends from the surface 11 into a potentially productive formation 12 containing fissures 13. A casing 14 extends from the surface to a level just above the formation 12 and is backed by a cement lining 15. The well bore in the formation is uncased.

The method may be used to fracture a formation adjacent a casing in a well, say, with several productive formations, but as with any fracturing procedure of this type, damage to the casing will result which creates substantial debris upon fracturing and must be repaired afterwards. To fracture a formation at a level above the bottom of the well bore, a bridge plug or packing plug is placed at the lower end of the formation to be fractured. Similarly, if it is desired to prevent downward fracturing, for example because of a water zone below the pay zone, the bottom of the well bore may be filled with sand before injecting in the slurry.

Before fracturing, the well bore should be cleaned of sludge, paraffin and the like by well-known techniques. Then, as illustrated in FIG. 2, a tube 16 is placed into the well extending from the surface to the formation. Tube 16 is provided at its lower end with a one-way valve 17 for permitting flow from the tube into the well bore while preventing flow in the opposite direction, from the well bore into the tube.

One-way valve 17 is a float valve comprising a constricted orifice 18 formed in the tube, and a spherical float shoe 19 forming the valve closure, suspended directly below and slightly spaced from the orifice on a spring 20 which rests on a shelf in the lower end of the tube. Other suitable one-way valves may be used.

An annular plug 22 is placed at the lower end of the casing to seal off the annular portion between tube 16 and the casing. Where the lower portion of the well bore is filled with fluids, the packing plug should not be sealed, however, until the slurry has been loaded into the well bore, as will become apparent. The slurry may then be poured into the top of the tube 16, either directly or through a tube connected to a container of slurry, for example, or the slurry may be pumped into the tube. By this means, the slurry is injected into the well bore directly at the formation 12 to be fractured, and is prevented from contacting fluids in the well bore before reaching the formation. Note that no fluid from the bore is permitted to enter the tube due to one-way valve 17. As the slurry fills the bottom of the well bore, since it is substantially more dense than the fluid in the well bore, such fluids (usually water and/or oil) are

displaced above the slurry and flow past packing plug 22 up into the well bore.

As shown in FIG. 3, when the desired amount of slurry has been placed in the well bore a wiper plug 23 is inserted into the top of tube 16 and the tube is then connected through a high pressure pump 24 to a source of, say, water. Packing plug 22 is then seated by conventional means to seal off the portion of the well bore adjacent the formation. The slurry below wiper plug 23 is then driven downward by the wiper plug under pump pressure, forcing the slurry in the tube and in the bore hole into fissures 13.

In some cases, it may be desired to hydraulically fracture the formation before explosively fracturing it. This may be done using the explosive slurry as a hydraulic fracturing fluid, merely by providing enough pressure at pump 24 to hydraulically fracture the formation.

The packing plug 22 is then unseated and removed along with the tube 16 from the bore hole. The level of the slurry in the bore may then be checked by lowering a temperature sensing device on a cable (not shown) into the well and noting the length of cable paid out when the temperature sensing device reaches the slurry. This point is easily determinable, as the slurry temperature is substantially lower than that of residual well fluids, which are usually at least 120° F. a 1,000 feet below the surface. A detonating device 24 containing a timer and a high explosive charge is then lowered into the well on a wire cable so that it is submerged in the slurry, and permitted to drop to the bottom of the well, still remaining completely surrounded by the slurry. The high explosive charge may be any suitable high explosive, such as TNT, and is included in the detonating device along with the timer (not shown) for presetting the device to explode after a predetermined interval.

A packing plug 25 (FIG. 4), commonly referred to as a bridge plug is then placed at the lower end of the casing to seal off the productive formation and protect the casing, and the well bore above packing plug 25 is filled with fluid to maintain a static pressure above the explosion. At the end of the predetermined interval, the detonating device is detonated by its internal timer, causing the slurry to explode. Bridge plug 25 may then be removed from the well and the debris resulting from the explosion cleaned out, after which time the well is ready for production.

The particular amount of slurry used for any given application will depend upon the nature of the well, the character of the formation to be fractured, and the extent of fracture desired, and may be different for each well. In general, it has been found that between 100 and 50,000 pounds of slurry is suitable for most applications, and generally between 500 and 5,000 pounds will be required.

The following examples illustrate particular embodiments of the invention.

EXAMPLE V

A generally productive well having a productive formation at about 2,000 feet and which had substantially ceased to produce was cleaned using conventional techniques. A water zone was known to exist a short distance below the pay zone, and in order to prevent downward fracturing into the water zone approximately 30 feet of sand was loaded into the bottom of the well bore. A tube with a one-way valve at its lower end was then inserted through the well bore into the formation, and an annular packing plug was lowered about the tube to the lower end of the well casing, just above the level of the formation. Slurry having the composition described in example I above was poured down through the tube into the formation. 4,200 pounds of slurry were used, after which a wiper plug was sent under pressure through the tube, so that about 25 percent of the slurry was pushed back into the formation. The tube and pumping equipment were then removed and the slurry level in the bore hole checked with a temperature sensing device. A TNT detonating device set for 2-hours delay

was then lowered on a wire line into the slurry, and the wire line reeled back. A bridge plug was then seated at the lower end of the casing, and the well bore above it was filled with water. It was ascertained before setting the bridge plug that the well bore was filled with water below the level of the plug, above the slurry. After detonation, the bridge plug was removed and the resultant debris cleaned out.

EXAMPLE VI

The method of example V was carried out, except that no sand was placed in the bore hole, since no water zone was known to exist below the pay zone. While a packing plug was used, it was not sealed, so that when pressure was applied behind the wiper plug, well fluids raised above the slurry merely rose in the bore hole. Consequently, it is estimated that only about 5—10 percent of the slurry flowed back into the formation. 1,200 pounds of the slurry of example I above were detonated in the bore hole, and approximately an 800 percent increase in production was determined; the well is continuing in production at this rate.

EXAMPLE VII

The method of example VI was carried out except that 800 pounds of the slurry of example III, above, were used. It is estimated that approximately 5 percent of the slurry flowed into the formation.

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.

We claim:

1. A method of fracturing a formation adjacent a well bore with a slurry explosive formed of nonhygroscopic granular solid explosive evenly dispersed throughout a dispersive medium in which it is insoluble and containing a gelling agent, which slurry is nondispersible in well fluids over a time period required to fracture the formation and thus capable of retaining its initial density until fracturing, comprising:

placing into said well bore a tube extending from the surface to said information and provided at its lower end with a one-way valve for permitting flow from the tube into the well bore while preventing flow from the well bore into the tube;

placing a packing plug in the well bore about said tube above said formation for sealing off that portion of the well bore adjacent the formation;

injecting said slurry through the tube and one-way valve into the well bore, leaving a substantial amount of slurry in said tube;

inserting a wiper plug into said tube and forcing the slurry therein under fluid pressure through the tube to pressurize the slurry into the formation and then removing

said tube and packing plug from the well bore;

lowering into said slurry, in the well bore, a detonating device containing a high explosive charge;

placing a packing plug in the well bore above said formation and filling the well bore above the slurry and above the packing plug with fluid, for maintaining static pressure above the formation during the explosion; and detonating the high explosive charge to explode the slurry, thereby fracturing said formation.

2. A method as defined in claim 1 wherein the detonating device includes a timer for detonating the high explosive charge after a preset interval, and detonation of the high explosive charge is initiated by said timer.

3. A method of fracturing a formation adjacent a well bore with a slurry explosive consisting essentially of a fluid dispersive medium capable of desensitizing a granular explosive dispersed therein; one or more granular solid explosives which are organic nitro compounds of high explosive power and which are nonhygroscopic and insoluble in the dispersive medium, evenly dispersed throughout the dispersive medium; and a gelling agent for maintaining the granular solid explosive evenly dispersed throughout the dispersive medium under conditions of pressure and temperature existing in well fracturing, said slurry explosive being nondispersible in well fluids over a time period required to fracture such formation, said method comprising:

injecting said slurry explosive into the well bore directly adjacent said formation through a tube extending from the surface through the well bore to a level adjacent the formation, such that the slurry cannot contact fluids in the well bore before reaching the formation;

placing a detonating device containing a high explosive charge within the slurry in the well bore; and detonating said high explosive charge to explode the slurry, thereby fracturing said formation.

4. A method as defined in claim 3 wherein said granular solid explosive is one or more organic nitro compounds selected from the group consisting of RDX, HMX, PETN and TNT, and constitutes about between 35 and 70 percent by weight of the slurry.

5. A method as defined in claim 4 wherein said dispersive medium is selected from the group consisting of water, alcohol, kerosene and hexane.

6. A method as defined in claim 4 wherein said dispersive medium is water and said explosives constitute about between 45 and 70 percent by weight of the slurry.

7. A method as defined in claim 6 wherein said gelling agent is Carbopol 941 and constitutes about 0.5 percent by weight of the slurry.

8. A method as defined in claim 3 wherein said dispersive medium constitutes about between 55 and 65 percent by weight of the slurry.