United States Patent

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[54] **EXPLOSIVE FRACTURING OF PETROLEUM BEARING FORMATIONS**
8 Claims, 4 Drawing Figs.

[52] **U.S. Cl.** **166/290,** 102/23, 166/299
[51] **Int. Cl.** **E21b 43/26**
[50] **Field of Search** 166/299, 308, 70, 153–156, 280, 290, 291; 102/20–23

[56] **References Cited**

UNITED STATES PATENTS

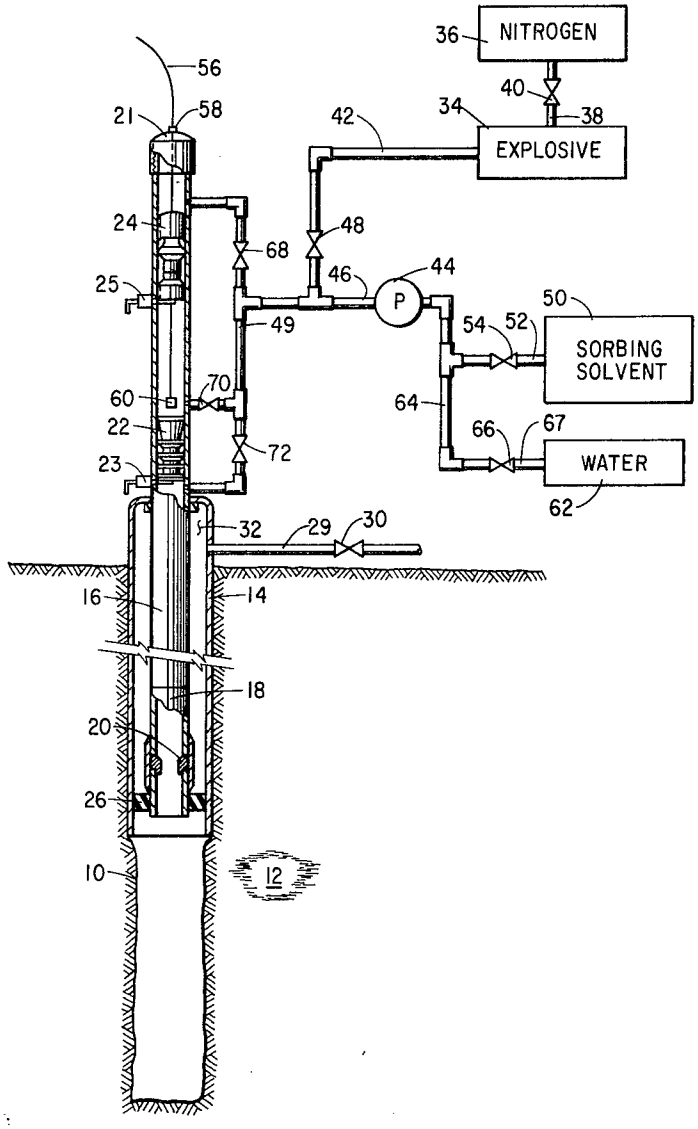
3,561,532	2/1971	Fletcher et al.	166/299
2,481,422	9/1949	Haynes et al.	166/70 X
2,708,876	5/1955	Nowak	166/299
2,892,405	6/1959	Chesnut	166/299
2,892,406	6/1959	Hradel et al.	102/23
3,075,463	1/1963	Eilers et al.	166/299
3,191,678	6/1965	Hinson	166/299
3,336,982	8/1967	Woodward et al.	166/299

OTHER REFERENCES

Frac Shot, Richmond, Va., Reynolds Metals Co., 1961

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ABSTRACT: This is a method for increasing the permeability of an underground formation adjacent a well bore by explosive fracturing. In one embodiment an explosive slurry, having selected fracturing fluid characteristics, is used to hydraulically fracture the formation and such explosive slurry is subsequently detonated. In another embodiment a sorbent solvent slug is injected down the tubing preceding the injection of the explosive slurry and a second such sorbent solvent immediately follows the explosive slurry. This avoids trapping of air or other gas and therefore prevents premature ignition or detonation of the explosive fracturing fluid.



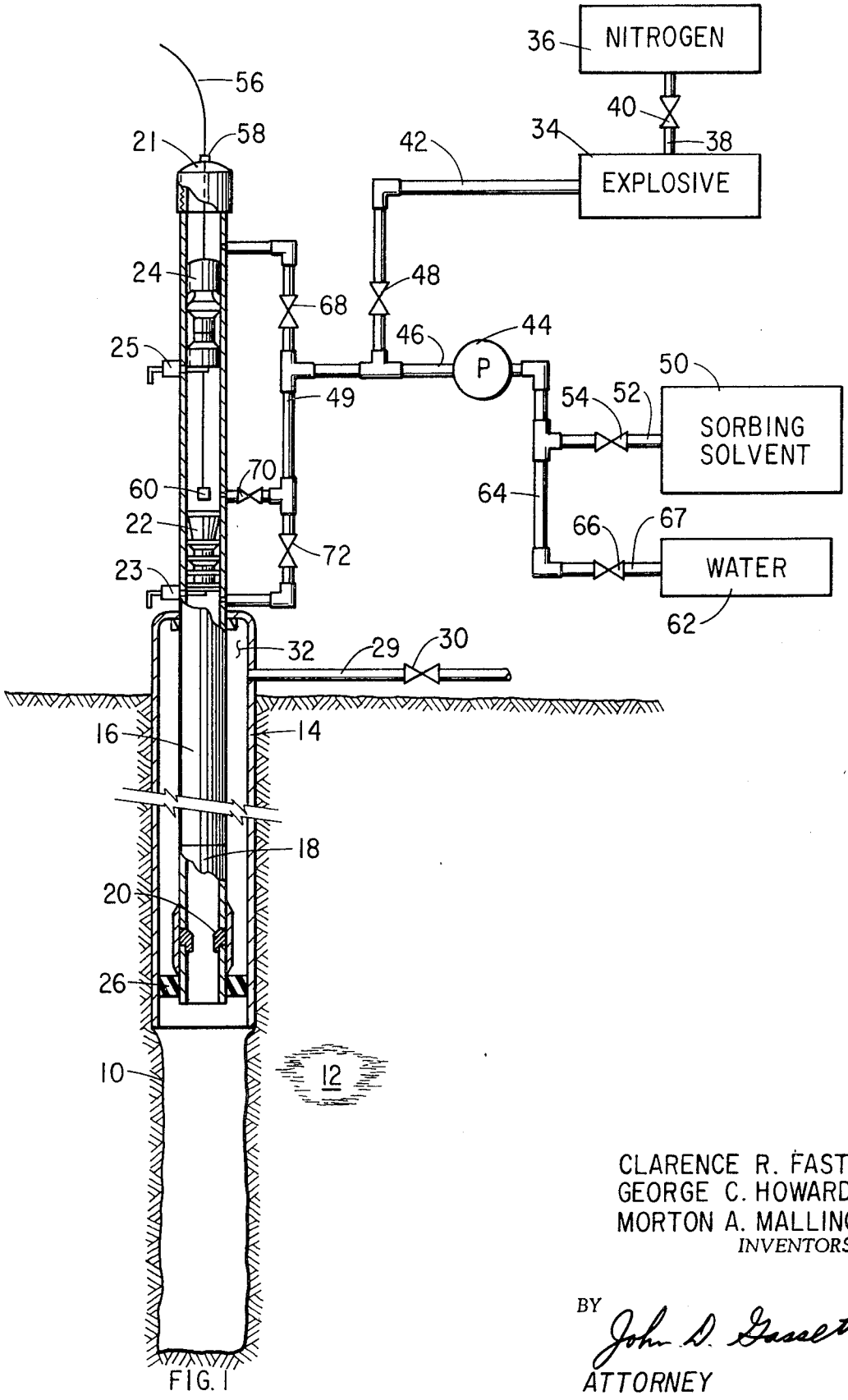


FIG. 1

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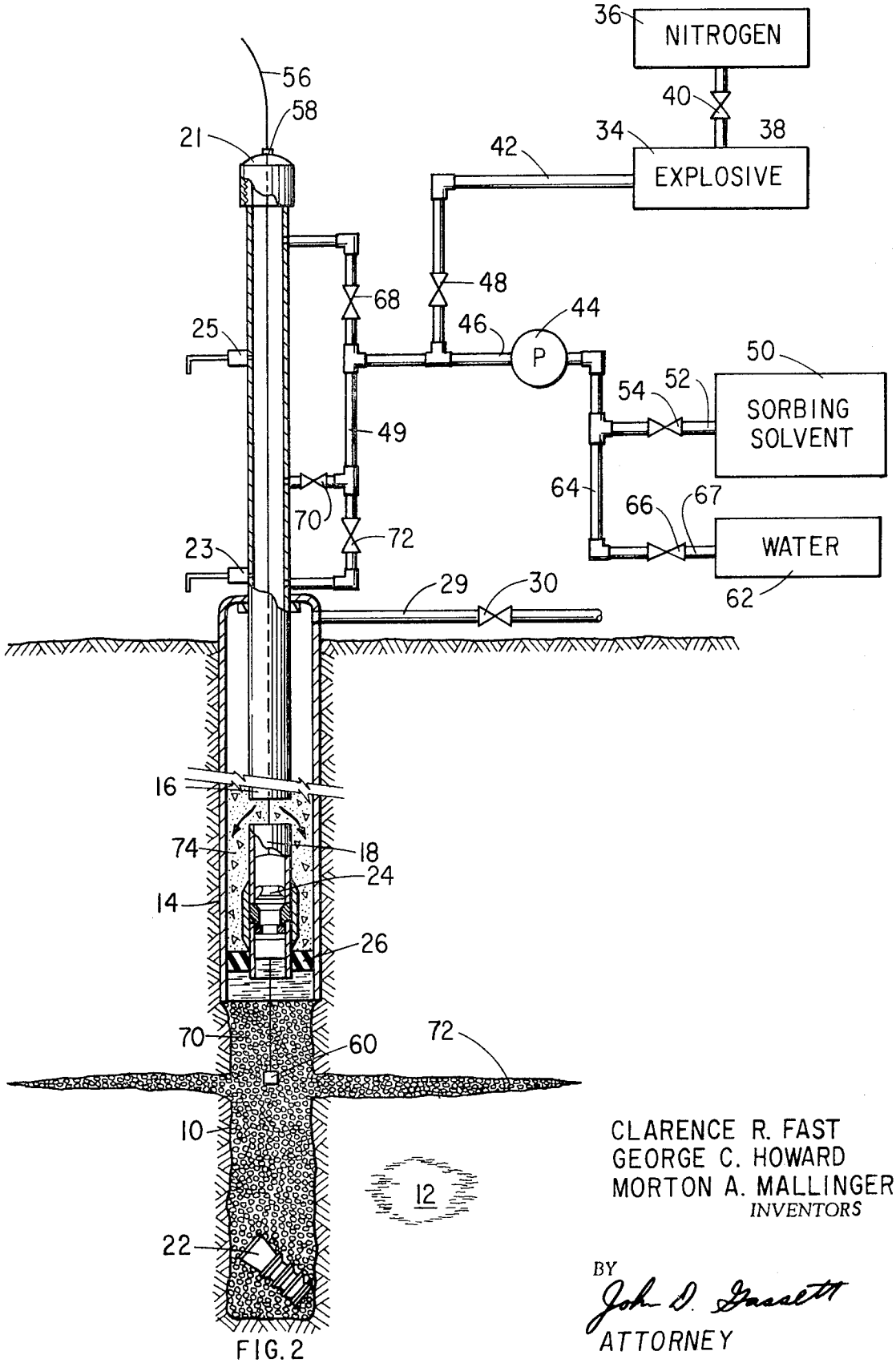


FIG. 2

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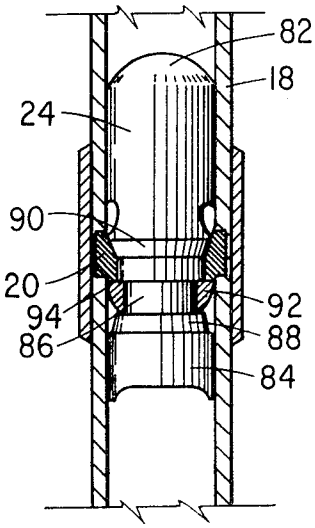


FIG. 4

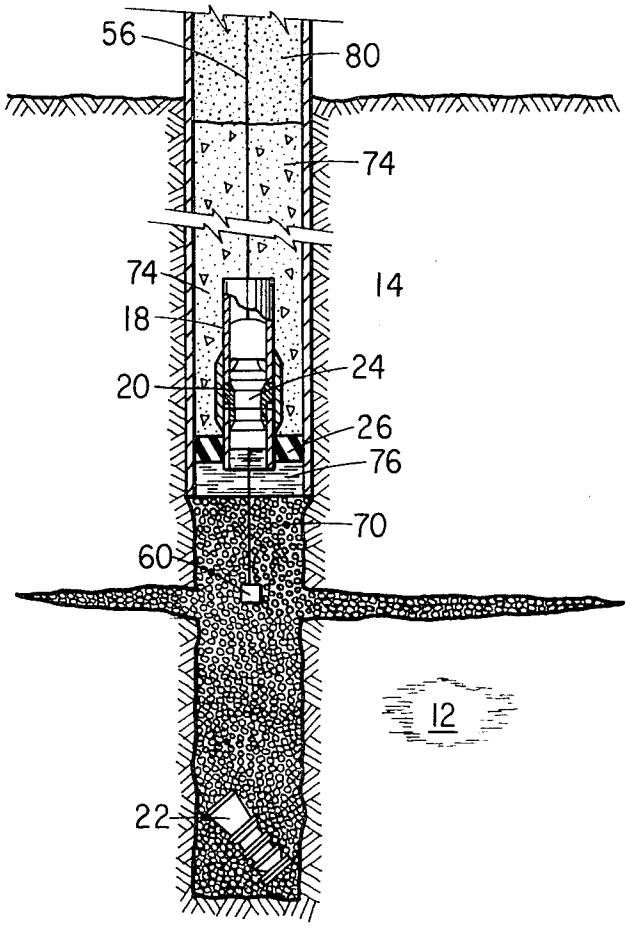


FIG. 3

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EXPLOSIVE FRACTURING OF PETROLEUM BEARING FORMATIONS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a method of increasing the permeability in a formation adjacent an oil and gas well which penetrates therethrough. It relates especially to a system in which an explosive fracturing fluid is used as a hydraulic fracturing fluid and is subsequently detonated. It also relates to ways of preventing premature ignition of the explosive fracturing fluid and a safer way of igniting the explosive fluid.

2. Setting of the Invention

Many oil and gas wells are drilled into petroleum bearing formations which have low permeability. That is, the formations are of a character that is difficult for the oil to be recovered; in other words, the formation is very reluctant to give up its petroleum. When such formation rocks are encountered, it becomes necessary to resort to one or more means to increase the permeability. One means which has been quite successful is the hydraulic fracturing technique. In this system a special hydraulic fracturing fluid is injected through the well bore adjacent to the formation. Fluid is continued to be pumped into the well bore so as to increase the pressure to the point where the formation is fractured. When this fracturing occurs there are usually propping agents left in the fractures so that the fractures will remain open, forming new paths for the oil to flow from the rock into the well bore. Frequently, this type stimulation does not result in desired production increases as it does not reach the unfractured matrix of the formation. Although hydraulic fracturing has permitted the production of billions of barrels of oil not heretofore recovered, there is still some room for improvement.

BRIEF DESCRIPTION OF THE INVENTION

An explosive slurry having fracturing fluid characteristics is injected into the well bore at a pressure and rate sufficient to fracture the formation. This explosive fracturing fluid is detonated in situ deep within the formation rock. In addition to the fracture caused by an explosive fluid acting as a fracturing fluid, many side fractures are formed when an explosive is detonated. Special precautionary steps are also taken to avoid trapping of air or other displacement gas which sometimes causes premature ignition or detonation of the explosive fluid. This is accomplished by injecting a slug of sorbent solvent, which is a desensitizer for the explosive used, immediately preceding the injection of an explosive slurry and a second such slug immediately following the injection of the explosive slurry.

DESCRIPTION OF THE DRAWINGS

Various objects and a better understanding of the invention can be had from the following description taken in conjunction with the drawings.

FIG. 1 is a vertical view, partly in section and partly schematic, of a well penetrating an underground producing formation.

FIG. 2 illustrates the lower end of a well bore which penetrates a producing formation in which the explosive liquid has penetrated the formation.

FIG. 3 illustrates stemming in a well in which an explosive liquid has been placed under pressure.

FIG. 4 is an enlarged view of one plug used in the tubing of FIGS. 1, 2 and 3.

DETAILED DESCRIPTION OF THE INVENTION

Attention is first directed to FIG. 1 which illustrates schematically a well equipped to carry out this invention. Shown thereon is a well bore **10** which penetrates a producing formation **12**. An upper part of borehole **10** is cased with a casing **14** cemented in place in a conventional manner. In this particular setting, casing **14** does not extend through the producing formation **12**. Suspended within casing **14** is a string of tubing **16** having a sub **18** at the bottom and a removable plug insertion head **21** on top containing a conductor cable-packing gland **58**. Sub **18** has plug catcher **20** on the inside thereof. As will be explained more fully hereinafter, catching means **20** permits plug **22** to pass therethrough but catch plug **24**. Plug **22** is shown retained in the upper part of the tubing by plug retainer pin **23** and is just immediately ahead of the explosive fluid. Plug **24**, retained by plug retainer pin **25**, trails the fracturing fluid. The details of plugs **22** and **24** and catching means **20** will be described in detail hereinafter. The lower end of the annulus between tubing string **16** and casing **14** is sealed by packer **26** which can be a drillable production packer. The upper or main part of tubing string **16** can be disconnected from sub **18** by simply rotating and lifting. This, as will be seen, is useful for placing cement in the well bore above packer **26**.

A pipeline **29** having valve **30** therein connects the annulus **32** of the well bore with a pit or tank not shown. This is useful in passing a fluid such as cement slurry into the casing **14** above packer **26**.

Attention will now be directed briefly toward that part of the equipment located on the surface which is used for injecting the liquid explosive into the well bore. This includes a container or source **34** having an explosive slurry or liquid therein. A nitrogen source **36** is connected through line **38** having valve **40** to drive the liquid explosive from container **34**. The outlet of container **34** is connected through line **42** to a wellhead manifold **49**. Line **42** has a valve **48** adjacent container **34**. The outlet of pump **44** is connected through line **46** to tubing string **16** through manifold **49**. Pump **44** is a high-pressure pump such as a triplex plunger positive displacement pump capable of exerting sufficient pressure and rate to fracture formation **12**. A sorbent solvent source indicated as container **50** is provided. This has an outlet line **52** which connects into line **64** leading to pump **44**. Line **52** has valve **54** therein adjacent container **50**. A water source **62** connects through conduit **67** to conduit **64**. Conduit **64** is connected to pump **44**.

An electric-conducting line **56** extends through a packing **58** in the upper end of tubing string **16**. This line **56** extends downwardly through top plug **24** and is connected to and supports an igniter or detonator **60**.

Characteristics of Liquid Explosive

In a preferred embodiment we propose to use the explosive liquid itself as the fracturing fluid. SUch fluid should have a fracturing fluid coefficient, C, of 0.01 feet per square root a minute, or less, (fluid coefficient, C, is a term which means volume lost per distance per unit of time or feet cubed/feet squared/time in square root of minutes) and a fluid loss of less than 100 cc. per 30 minutes (API), be essentially water immiscible and somewhat oil miscible. The water immiscibility allows the displacement of the liquid explosive down the tubing string with water. On the other hand, the oil miscibility insures desensitization of the explosive during the production phase. Additionally, the liquid explosive should be capable of transporting propping agents, such as sand or predominantly aluminum, into the fracture. This means that the liquid explosive should have a plastic viscosity of greater than 100 cp. This liquid explosive must be able to support detonation in the narrow confines of the fracture of a formation which may, in some cases, be less than about one thirty-second inch. A suitable liquid explosive is one in which nitromethane is the predominant composition and contains a thickening agent, sensitizer and other additives tailored to the bottom-hole temperature, pressure and type formation. A suitable commercially available liquid explosive is Ta1–1005, which is available from Talley Industries, Inc., Mesa, Arizona. Nitromethane-based liquid explosives are especially desirable as they can be ignited and if the pressure builds up, the deflagration will progress to high-order detonation and unburned nitromethane will detonate, causing the desired explosion. We show means to confine the nitromethane-based

liquid explosive in the well bore. We can then use a flame igniter. The liquid explosive then can be flame squibbs and a propellant. This is much safer than a time bomb containing a high explosive.

Operation System

A sorbent solvent from container **50** is released through line **52** with valve **54** open to line **64**. This goes in through manifold **49** on top of bottom plug **22**. In the past, attempts to displace liquid explosives in oil wells, resulted in the explosives being placed in the tubing string and then followed by a displacing plug. During displacement operations, air, displacing gas, or vapors from the explosive are injected on top of the bottom plug. Under some conditions, these mixtures of air, displacement gas, and vapors when compressed under bottom-hole temperature can cause explosives to ignite or detonate prematurely. We overcome this problem by injecting a slug of sorbent solvent into the tubing just above bottom plug **22** and into the tubing string just below top plug **24** after all liquid explosive has been pumped into the tubing string. A sorbent solvent suitable for this type operation is one that desensitizes the explosive and, for example, can be dibutyl phthalate, toluene, benzene, or the like. This sorbent combination or solvent absorbs or dissolves any gas and desensitizes any explosive with which it comes into contact. No compounds containing an explosive sensitizer such as amines or acids should be used as sorbents.

Having described the suitable liquid explosives and a suitable sorbent solvent, attention will now be directed toward their injection. As mentioned, a slug of sorbent solvent is injected on top of plug **22**. This volume should be enough to occupy several feet of tubing string. At this time valve **54** is closed and valve **48** is opened, thus connecting the liquid explosive container **34** with manifold **49**. This liquid is displaced by nitrogen into the tubing string at the selected pressure and rate of flow. Continued pressuring of the liquid explosive forces the bottom plug **22** downward through the bottom end of the tubing string when it drops down to the borehole bottom. The injection of the liquid explosive continues as desired. If it is desired that the liquid explosive be used as a hydraulic fracturing fluid, then sufficient fluid is injected under sufficient pressure to cause such fracture. Quality and characteristics of hydraulic fracturing fluid are well known. When the total amount of liquid explosive is injected into the well, valve **48** is closed, closing off the liquid explosive source, and valve **54** is opened and a second slug of sorbent solvent is injected into the tubing, this time on top of the explosive liquid just below top plug **24**. This is done by opening valve **70** and closing valves **68** and **72**. Top plug **24** is then displaced downwardly by closing valve **54** and opening valve **66** connecting the pump to the water source **62** and valve **68** is opened and valves **70** and **72** are closed, after which water is pumped on top of top plug **24**. When the top plug reaches locking means **20** it is locked in position which confines the liquid explosive in the borehole below packers **26** as shown in FIG. **2**.

Bottom plug **22** is a conventional cementing tubing wiper plug with a soft outer elastomer body and a hard metal or plastic core. The plug is designed to wipe the pipe walls clean as it moves down the tubing. The dimensions of plug **22** are such that the plug will pass through top plug latching means **20** shown in FIG. **4**.

Top plug **24**, sub **18** and plug latching means **20** are shown in detail in FIG. **4**. Latching means **20** is simply a reduced diameter steel ring that is fitted in sub **18**. Top plug **24** consists of elastomer wiper portions **82** and **84** connected by steel center portion **86**. The dimensions of center portion **86** are such that the bottom part **88** of the center portion **86** of plug **24** will pass through latching means **20**. The top part **90** of center portion **86** of plug **24** is preferably a metal ring which will not pass through latching means **20**. Plug **24** also contains latching ring **92** which is a split spring steel ring that compresses on passing through latching means **20** and expands after passing through so that latching ring **92** bears against shoulder **94**, thereby locking plug **24** in place so that it cannot move upward. Top part **90** of the plug prevents downward movement. Top plug **24** and catcher **20** are commercially available from Baker Oil Tools, Inc., Los Angeles, California, and are identified as Model C Cementing Plug and Full Flow Fill Up Collar.

As shown in FIG. **2**, the liquid explosive **70** fills the borehole and extends out into fracture **72**. The flame igniter or explosive detonator **60** is positioned in the liquid explosive **70**. It is also seen that the bottom plug **22** has dropped down to the bottom of the borehole. At this point, the upper part of tubing string **16** has been disconnected from sub **18**. At this time, cement slurry is displaced down tubing string **16** and out the lower end thereof and onto the upper side of packer **26** and upper plug **24**. This placing of the cement **74** is the first step of the important stemming of the explosive.

Attention is next directed to FIG. **3** which illustrates the liquid explosive extending out into the fractures filled by the liquid explosive and in which such liquid explosive is stemmed. Show thereon is the liquid explosive **70** with a sorbent solvent **76** just below packer **26**. Above packer **26** is about 100 feet of cement **74**. It has been found that about 100 feet will ordinarily be adequate. Immediately above cement **74**, sand **80** has been placed and extends a few hundred feet up into the casing. The remainder of the hole is filled with water to the surface. This stemming does two things: 1. It prevents the explosive from damaging the casing **14** and keeps the explosive force at the formation. 2. This confines the liquid explosive and in the case where the liquid explosive is predominantly sensitized nitromethane, detonation can be accomplished by the use of a flame igniter. Thus, when it is time to set off the explosive composition, an electrical current is sent down wire **56** to ignite the flame igniter or explosive detonator. In the case where a flame igniter is used, the burning nitromethane reverts to high-order detonation if the pressure generated is not relieved. As this liquid **70** is confined below the stemming, the pressure is confined, thus high order detonation occurs. There is quite an advantage to the technique of igniting nitromethane mixtures because an igniter is much safer to handle than a detonator, which is a high explosive initiated by a dangerous blasting cap.

Tests were conducted to evaluate the use of a sorbent solvent preceding and following the injection of a flammable liquid explosive to the well to prevent ignition. The tests were conducted in a pressure chamber fitted with an electrical heating unit and a thermocouple. A 1 milliliter sample of TAL–1005C liquid explosive (produced by Talley Industries Inc., Mesa, Arizona) was placed in the chamber and gas pressure held in the chamber with the thermocouple immersed in the explosive. Heat was applied to the chamber at a low rate and the temperature of the explosive measured until it ignited. Ignition was observed by a very sharp increase in temperature. The following results were observed:

Pressure	Gas	Ignition Temp. °F.
ATM	O_2	536
1,000	O_2	428
1,000	N_2	482
2,000	O_2	392
2,000	N_2	500

These tests show that at a given pressure, the ignition temperature of a liquid explosive, in this test an explosive identified as TAL–1005C, produced by Talley Industries, Inc., Mesa, Arizona, is appreciably lower with oxygen present than with nitrogen. They also show that the ignition temperature of the explosive decreased with increasing temperature when oxygen was present but did not when the explosive was in a nitrogen atmosphere. These tests then suggest that a liquid sorbent should be injected preceding and following the liquid explosion to sorb any volatilized explosive that is produced when the well is on vacuum during explosive displacement.

While the above embodiments of the invention have been described with considerable detail, it is to be understood that various modifications of the device can be made without departing from the scope or spirit of the invention.

We claim:

1. A method of explosively fracturing a formation penetrated by a well bore which comprises:

a. injecting a first slug of a sorbent solvent into said well bore, the sorbent solvent used in this method being capable of desensitizing said liquid explosive which it contacts;

b. immediately following step (a) with the injection of a liquid explosive;

c. following step (b) immediately with injection of a second slug of a sorbent solvent; and

d. thereafter detonating said explosive liquid.

2. A method as defined in claim 1 including the step of stemming said liquid explosive above said second slug of sorbent solvent.

3. A method as defined in claim 1 in which said sorbent solvent is selected from the group consisting of dibutyl phthalate, toluene and benzene.

4. A method of using a liquid explosive to fracture an underground formation penetrated by a well bore in which a string of tubing is suspended which comprises:

inserting a bottom plug in said string of tubing;

placing a packer about the lower end of said string of tubing to seal the annulus between the string of tubing and the well bore;

injecting a first slug of sorbent solvent on top of said bottom plug, the sorbent solvent used in this method being capable of desensitizing said liquid explosive which it contact;

injecting said liquid explosive into said tubing string on top of said first slug, continuing injecting said liquid explosive until a selected amount has been injected and driving said bottom plug through the lower end of said tubing string;

injecting a second slug of sorbent solvent into said string of tubing on top of said liquid explosive;

inserting a top plug on top of said second slug;

displacing said liquid explosive, said second slug and said top plug down said tubing string until said top plug reaches the lower end of said tubing string;

retaining said top plug in the lower end of said tubing string;

placing stemming material on top of said annulus packer and said top plug;

thereafter detonating said explosive liquid.

5. A method as defined in claim 4 wherein said step of placing stemming material comprises separating the tubing string from a lower section thereof and injecting cement down through said tubing string and onto the top of said top plug and said packer; and

removing said tubing string as said cement is displaced into said well.

6. A method as defined in claim 5 in which there is about 100 feet of cement placed above said annulus packer and said top plug.

7. A method of explosively fracturing a formation penetrated by a well bore which comprises:

a. injecting a liquid explosive into said well bore;

b. immediately following step (a) injecting a slug of sorbent solvent, the sorbent solvent used in this method being capable of desensitizing said liquid explosive which it contacts; and

c. thereafter detonating said liquid explosive.

8. A method as defined in claim 7 wherein said liquid explosive and said sorbent solvent is directed down through a string of tubing and including the step of inserting a top plug in said string of tubing above said slug of sorbent solvent.

* * * * *