ABSTRACT: This is a method for increasing the permeability of an underground formation adjacent to 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.
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 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 under 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 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 the 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 for-
liquid explosive in the well bore. We can then use a flame igniter. The liquid explosive then can be flame squibs 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 dibuty phthalate, tolulene, 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 top 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 the plug 24. When the top plug approaches 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 center 86 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. Shown 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 a 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 thermostatic chamber. 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 thermostatic mixture 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:

<table>
<thead>
<tr>
<th>Pressure</th>
<th>Gas</th>
<th>Ignition Temp. °F.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATM</td>
<td>O2</td>
<td>536</td>
</tr>
<tr>
<td>1,000</td>
<td>O2</td>
<td>428</td>
</tr>
<tr>
<td>1,000</td>
<td>N2</td>
<td>482</td>
</tr>
<tr>
<td>2,000</td>
<td>O2</td>
<td>392</td>
</tr>
<tr>
<td>2,000</td>
<td>N2</td>
<td>500</td>
</tr>
</tbody>
</table>

These tests show that at a given pressure, the ignition temperature of a liquid explosive in this test is 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 the liquid explosive 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 contacts;
   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.

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