Feb. 6, 1962 D. L. HARLAN ETAL 3,019,838

WELL BORE COMPLETION METHOD

Filed Dec. 30, 1959 2 Sheets-Sheet 1

Fig. 1.

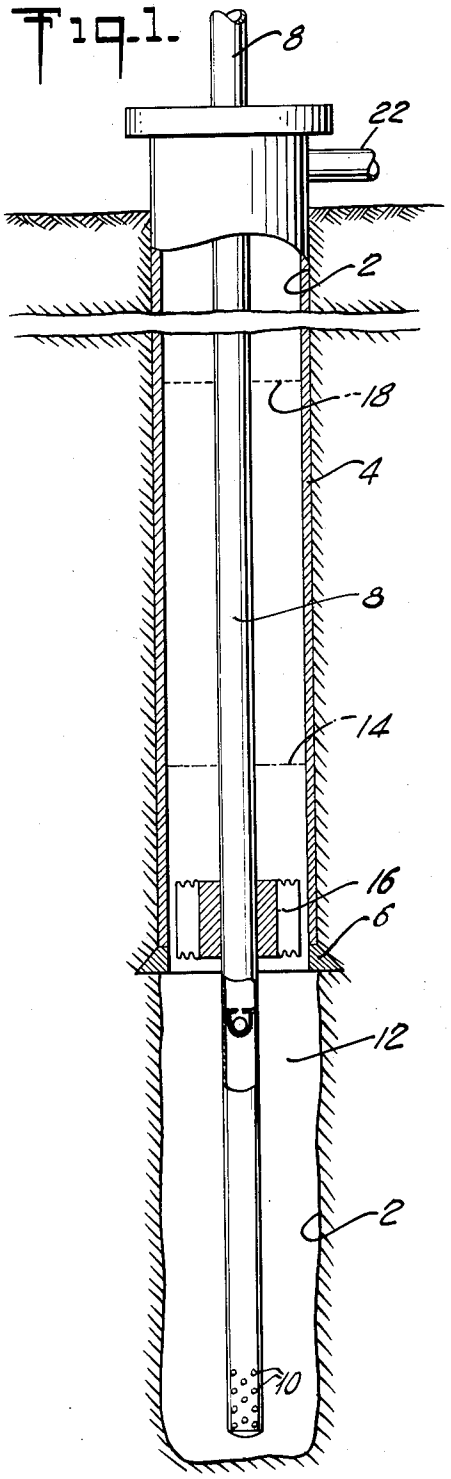
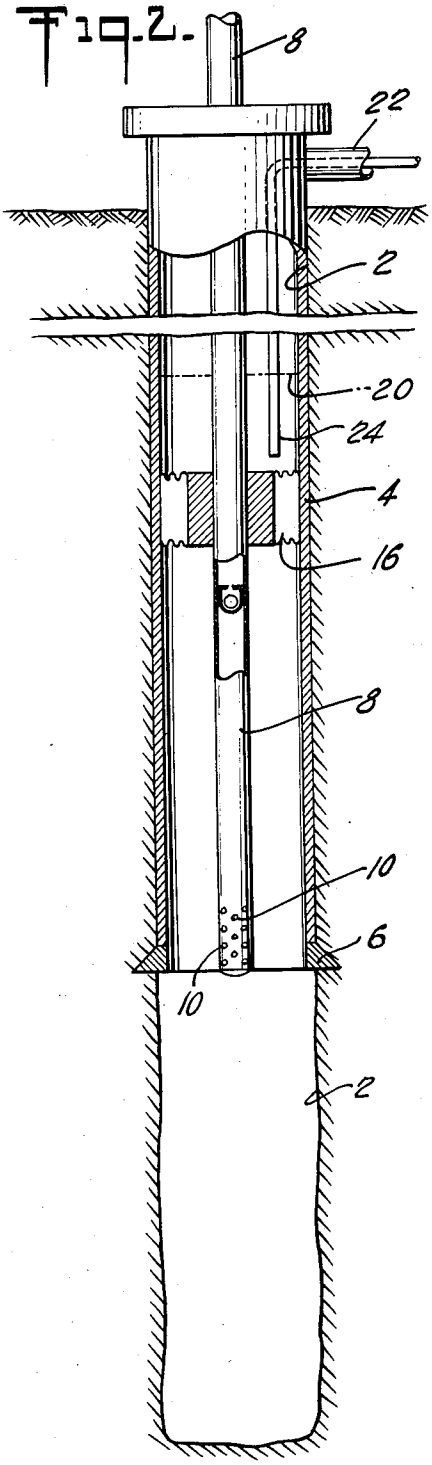


Fig. 2.



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Fig. 3.

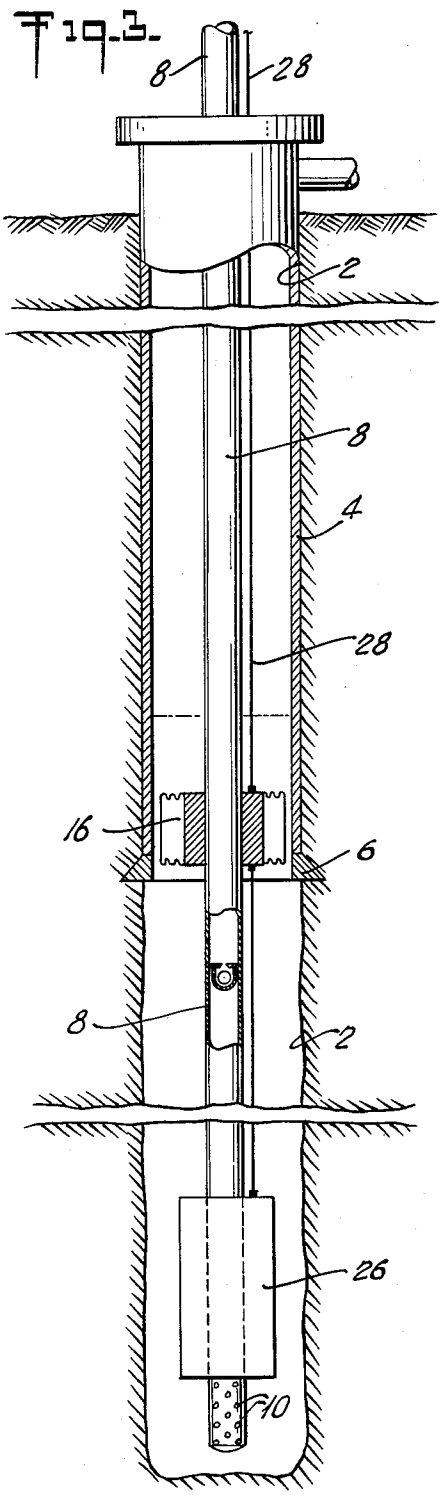
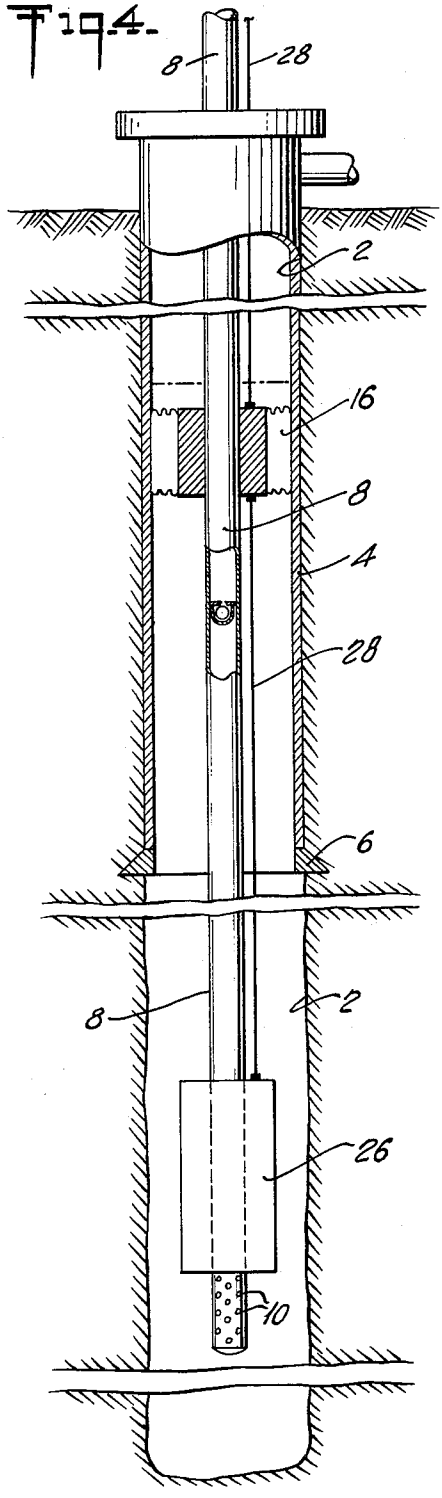


Fig. 4.



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3,019,838
WELL BORE COMPLETION METHOD

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8 Claims. (Cl. 166—39)

This invention relates to a method of preparing a well bore prior to initiation of a procedure for the recovery of hydrocarbons contained in an underground formation. More particularly, it relates to a method of preparing a well bore which contains a column of oil to make the initiation of a thermal recovery procedure relatively safe.

Recovery procedures in which a combustion-supporting gas such as oxygen or air is used to either drive the oil from the formation or to support in situ combustion are hazardous from the standpoint of explosions in the well bore caused by the accidental ignition of combustible mixtures of fluid hydrocarbons and the combustion-supporting gas. Such explosions cause damage to expensive well producing equipment and in some cases cause harm to personnel and equipment at the surface above the well. Thus, it is necessary for the safety of personnel and equipment to remove oil from the well bore before initiating recovery processes wherein a combustion-supporting gas is injected into the well. In the process of removing the standing volume of oil from the well, water or other non-combustible, heavier-than-oil liquid is desirably utilized to lift the oil from the well bore. However, when the oil is removed in this manner, a large volume of water is left in the well bore and the surrounding formation. It is generally believed that the introduction of water into the hydrocarbon-containing formation is harmful to the formation from the standpoint of the production of hydrocarbons.

In accordance with the present invention, the method of preparing a well bore containing a standing volume of oil for a secondary recovery process in which a combustion supporting gas is introduced through the well bore into a surrounding underground hydrocarbon-containing formation, and said recovery process employs producing equipment including a tubing string having fluid-tight well sealing means, generally referred to as a packer affixed at a point along its length, comprises inserting said tubing string into the well bore, introducing a non-combustible heavier-than-oil liquid into said well bore in an amount sufficient to raise the oil-non-combustible liquid interface to a level just above that at which the packer will be set for the recovery process, setting said packer at the desired level for the recovery process, introducing a non-combustible fluid into the well bore above the packer whereby substantial pressure is exerted downwardly against the packer, and initiating said secondary recovery process in the formation adjacent the lower portion of the well bore. The heavier-than-oil, non-combustible liquid is preferably water or brine as both of these are readily available near most oil leases. In order to prevent excessive turbulence in the introduction of the non-combustible, heavier-than-oil liquid into the standing column of oil in the well bore, the open lower end of the tubing string is positioned close to the bottom of the well bore and the liquid is introduced at the bottom of the well bore through the tubing string. When the oil-liquid interface reaches the required level, the tubing string is lifted until the producing equipment is at the desired level and the packer is set to provide a fluid-tight seal in the annulus formed between the well casing and the tubing string.

Non-combustible fluids which are used to pressurize the packer include, for example, inert gases such is nitrogen, which is injected into a well bore properly sealed at the well head, carbon dioxide or gases consisting principally thereof, and water and liquids consisting principally thereof such as brine. Oil lifted to the annular space above the well sealing means does not constitute a hazard when employing inert gas to pressurize the annular space above the packer. Inert gas such as nitrogen is advantageously used in instances when it is undesirable to permit water or brine above the packer to go into the formation when the packer is unseated.

When introducing water or other similar liquid into the well bore above the packer it is desirable to inject it below the oil-water interface by means of tubing or hose inserted in the annulus of the well bore. This helps prevent the formation of emulsion and keeps the water and oil in separate phases. Water is continuously introduced until the entire column of oil is removed at the well head.

The position of the packer is determined by the final position of the producing equipment hanging below the sealing means. This is necessarily so since the distance between the packer and the equipment below it is fixed at the time it is lowered into the well.

A more complete understanding of the invention will result from reading the following specification in conjunction with the accompanying drawing in which:

FIG. 1 is a diagrammatic sectional view of a well bore containing equipment in position for the initial steps of the invention.

FIG. 2 is a diagrammatic sectional view of the well bore and equipment of FIG. 1 having the equipment in position for the final steps of the invention.

FIG. 3 is another diagrammatic sectional view of a well bore containing other equipment for thermal recovery positioned for the initial steps of the invention; and

FIG. 4 is a diagrammatic sectional view of the well bore of FIG. 3 showing the equipment positioned for the final steps of the invention.

In FIG. 1, producing equipment has been placed in well bore **2** having casing **4** and casing shoe **6**. The equipment has been assembled so that the lower end of tubing string **8**, having perforations **10**, is at or near the bottom of the well bore **2**. The well bore **2** as shown in FIG. 1 contains a standing column of oil **12** having oil-gas interface **14**. Thus, tubing string **8** having its lower end near the bottom of the well bore can be used as a means to discharge or inject a fluid at the bottom of the column of oil **12**. Packer **16** is shown unset and positioned as low as possible in the casing **4**.

A non-combustible liquid which is heavier than oil, such as water, is pumped down tubing **8** and injected through perforations **10** at the bottom of the column of oil **12**. The injection of water is continued until the column of oil is lifted to a place in the well bore where the oil-water interface is just above the level at which the packer is to be set for the initiation of a thermal recovery procedure. The position of the packer is determined by the desired position of the producing equipment hanging below it. In the arrangement shown in FIGS. 1 and 2 in which the equipment is designed for an in situ combustion procedure wherein combustion is initiated spontaneously by the introduction of chemicals, it is desirable to position the lower end of the tubing string just inside the casing **4**. Thus, when oil-water interface reaches the level shown by dotted line **18** in FIG. 1 and line **20** in FIG. 2, tubing string **8** is moved upwardly to place the lower end thereof in the desired position within casing **4** and consequently positioning packer **16** just below oil-water interface **20** in FIG. 2.

Packer **16** is set to provide a fluid-tight seal and water is introduced through opening **22** of casing **4**. The pre-

ferred method of introducing water into the annulus formed by tubing 8 and casing 4 above set packer 16 is through a small tubing 24 inserted into the annulus and reaching to a level beneath interface 20 so that the water is injected with little turbulence beneath the interface. This method prevents the formation of emulsions and maintains separation of oil and water while the water column slowly displaces the oil through opening 22 at the top of the casing 4.

It has been found that in some instances it is not necessary to have the small tubing 24 inserted in the annulus to a level beneath interface 20. Water has been successfully injected into the annulus with the small tubing 24 inserted only about 10 to 30 feet below the well head at opening 22. In this case, the water efficiently gravitated in the annulus to the packer 16 and effectively raised and displaced the oil out of opening 22.

When the oil has been removed from the annulus, water injection is terminated leaving a standing column of water over packer 16.

As previously stated, there are times when it is undesirable to pressure packer 16 with water. Therefore, an alternate method of pressurizing the packer 16 is to inject an inert gas into the annulus above the packer while maintaining a reasonably gas tight seal at the well head. The oil column located in the annulus above the packer will add to the pressure on the packer without hazard.

The method of completing a well for recovery operations employing a combustion-supporting gas wherein downward pressure is applied to a fluid-tight seal in the well bore, is disclosed and claimed in copending application S.N. 863,044, filed of even date herewith by Charles D. Woodward and Billy H. Towell.

The well bore is now ready for the preparation of the formation for an in situ combustion process or other thermal recovery process using air or other combustion-supporting gas as a drive to force hydrocarbons from the formation.

In preparing the hydrocarbon-bearing formation for an in situ combustion procedure, air is pumped through the tubing string 8 into the well bore below packer 16. The initial volume of air entering the well bore drives the relatively small amount of water therein into the formation. Thereafter sufficient pressure is supplied to establish permeability to adjacent well bores traversing the formation. As previously discussed, the mixture of a combustion-supporting gas and fluid hydrocarbons in the confinement of the well bore is hazardous. The oil which was displaced by water from the well bore was removed because of this hazard. It was removed by the method employed in order to prevent too much water from going into the formation and to complete the well in a manner designed to reduce the possibility of a downhole explosion. Any explosion in the relatively small diameter tubing string would be inconsequential and an explosion occurring in the annulus below the packer would be effectively dampened by the pressurized packer.

When permeability has been established in the formation, in situ combustion is established by either mechanical or chemical means. The equipment shown in FIGS. 1 and 2 is used for in situ combustion initiated by chemical means. The equipment shown in FIGS. 3 and 4 can be used for thermal recovery processes wherein heating or ignition is caused by mechanical heaters such as gas fired or electrical resistance units. In FIGS. 3 and 4, the apparatus differs principally from that shown in FIGS. 1 and 2 by the inclusion of a heater or ignitor 26 positioned around and at the lower end of tubing string 8. Heater 26, as shown is electrically powered by means of power cable 28 which runs through packer 16 without impairing its ability to produce a fluid-tight seal. After injecting sufficient water at the bottom of the well bore to raise the oil-water interface to a level high enough to allow packer 16 to be set just below the interface after the heater 26 is placed in the desired position for the in situ combustion procedure, the packer is set and fluid is introduced above the packer. When hazard of explosion has been reduced, air or other combustion-supporting gas is injected into the lower portion of the well bore through tubing 8. The introduction of air pushes the water remaining in the lower well bore into the formation and the continued air injection establishes permeability through the formation to adjacent production well bores. Power is transmitted through cable 28 to the heater 26 which becomes heated to a temperature sufficient to ignite the hydrocarbons near the well bore to establish combustion.

The following is an example of the process of this invention for initiating an in situ combustion by chemical means as performed in a producing well in the western United States.

Example

The producing string of the well was removed and the well cleaned out to its total depth. Clean tubing, with perforated nipple attached to the lower end of the tail pipe was run into the well for about 160 feet. A check valve was included in this length of tubing. A packer was assembled with the tubing at this point and the tubing was then run to within one foot of the bottom. Fifty barrels of water was circulated into the tubing, raising the oil-water interface to a point above the final packer setting. The tubing was lifted placing the end of the tail pipe opposite the casing shoe (3343 ft.) and the packer was set just beneath the oil-water interface at 3178 ft. The annulus above the packer was filled with water to remove all the oil.

Air was injected through the tubing string into the lower portion of the well using a low stage compressor. The well head pressure had stabilized within 24 hours at about 250 p.s.i. and the well was taking air at the rate of 200,000 standard cubic feet per day. Adjacent wells were monitored for gas and air production. For the next five days air was injected at the rate of 400,000 cubic feet per day at a well pressure of 240 p.s.i. After the first 3 days of air injection the closest adjacent well began to produce gas. On the fifth and sixth days five other adjacent wells were producing gas. Air injection was stopped after the sixth day. After about seven days the gas production of all the adjacent wells returned to normal. The well was purged with nitrogen injected through the tubing string. Thereafter, formation water was injected at a volume equal to the borehole and four barrels of chemicals (fatty acid extract from linseed oil) were pressured down the tubing string. The extract was displaced from the tubing string with nitrogen and the borehole was purged with nitrogen. Air injection was commenced through the tubing string at a rate of about 100,000 standard cubic feet per day and, after about three hours, well head injection pressure was steady at 170 p.s.i. At this time the pressure rose sharply to 185 p.s.i. and remained constant. After seven days the air injection rate was raised to 430,000 standard cubic ft./day and the well head injection pressure was 240 p.s.i. Gas production from one adjacent well increased from 2000 standard cubic feet per day to about 14,400 s.c.f./d. The gas production from another adjacent well doubled and the oil production from the same well rose from 40 to 54 bbls./day. Five days later another adjacent well was producing gas at 17,000 s.c.f./d. from a normal 1,750 s.c.f./d. Another adjacent well which was not producing measurable quantities of gas prior to the injection of chemicals (linseed oil) now produced 76,000 s.c.f./d. Still another adjacent well increased oil production from 2 to 11 bbls./day. The preparation of the injection well in accordance with the invention prior to combustion produced a safer and more convenient well bore for the establishment and maintenance of the secondary recovery operation described in the foregoing example.

Obviously many modifications and variations of the invention, as hereinbefore set forth, may be made without

departing from the spirit and scope thereof, and therefore only such limitations should be imposed as are indicated in the appended claims.

We claim:

1. In the recovery of hydrocarbons contained in an underground formation traversed by at least one well bore and where a combustion-supporting gas is injected into the formation through a tubing string positioned in said well bore, said tubing string having a packer affixed at a point along its length, the method of preparing said well bore containing a column of liquid hydrocarbons for the recovery operation which comprises introducing a non-combustible, heavier-than-oil liquid into said well bore while maintaining the packer affixed to the tubing string in a retracted position in an amount sufficient to raise the oil-non-combustible liquid interface to a level just above that at which the packer is to be set for said recovery operation, raising the tubing string and packer affixed thereto and, setting said packer below the level of said liquid interface to form a fluid-tight seal between the tubing string and the wall of the well bore at the desired level for the recovery operation, introducing a non-combustible fluid into the well bore above the set packer whereby substantial pressure is exerted downward against the packer, providing a combustion-supporting gas to said well bore below the set packer to drive the relatively small amount of non-combustible, heavier-than-oil liquid remaining in this part of the well bore into the formation and to establish permeability to adjacent well bores traversing the formation, and initiating said recovery operation in the formation adjacent the lower portion of the well bore.

2. In the recovery of hydrocarbons contained in an underground formation traversed by at least one well bore and where a combustion-supporting gas is injected into the formation through a tubing string position in said well bore, said tubing string having a packer affixed at a point along its length, the method of preparing said well bore containing a column of liquid hydrocarbons for the recovery operation which comprises first inserting said tubing string into the well bore, the lower end of said tubing string being positioned substantially at the bottom of said well bore, introducing a non-combustible, heavier-than-oil liquid at the bottom of said well bore through said tubing string while the packer affixed thereto is maintained in retracted position in an amount sufficient to raise the oil-non-combustible liquid interface to a level just above that at which the packer is to be set for the recovery operation, raising said tubing string to the desired level for the recovery process, setting said packer in fluid-tight sealing arrangement between the tubing string and the wall of the well bore below said liquid interface, introducing a non-combustible fluid into the well bore above said packer whereby substantial pressure is exerted downwardly aaginst the packer, introducing a

combustion-supporting gas under pressure into the well bore below the set packer to drive the heavier-than-oil liquid remaining in the lower portion of the well bore into the formation and to establish permeability to adjacent well bores traversing the formation, and initiating the recovery operation in the formation adjacent the lower portion of the well bore.

3. The method of preparing a well bore of claim 2 wherein the non-combustible, heavier-than-oil liquid is an aqueous liquid.

4. The method of preparing a well bore of claim 2 wherein said non-combustible fluid is an inert gas.

5. The method of preparing a well bore of claim 2 wherein said non-combustible fluid is an aqueous liquid.

6. The method of preparing a well bore of claim 5 wherein the aqueous liquid is introduced into the well bore above said set packer and below the oil-non-combustible liquid interface.

7. In the recovery of hydrocarbons contained in an underground formation traversed by at least one well bore and where air is injected into the formation through a tubing string positioned in said well bore, said tubing string having a packer affixed at a point along its length, the method of preparing said well bore containing a column of liquid hydrocarbons for an in situ combustion operation which comprises first inserting said tubing string into the well bore, the lower end of said tubing string being positioned substantially at the bottom of said well bore, introducing an aqueous liquid at the bottom of said well bore through said tubing string while maintaining the packer affixed thereto in a retracted position in an amount sufficient to raise the oil-aqueous liquid interface to a level just above that at which the packer is to be set for the in situ combustion operation, raising said tubing string to the desired level to carry out an in situ combustion operation, setting said packer below said liquid interface to form a fluid-tight seal between the tubing string and the wall of said well bore, introducing an aqueous liquid into the well bore above said packer but below the oil-aqueous liquid interface, injecting air through said tubing string to drive the aqueous liquid below the set packer into the formation, and initiating in situ combustion adjacent said well bore in the hydrocarbon-containing formation.

8. The method of preparing a well bore of claim 7 wherein in situ combustion is initiated by the injection of a spontaneous ignition type chemical through said tubing string into the formation and thereafter injecting air through said tubing string.

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