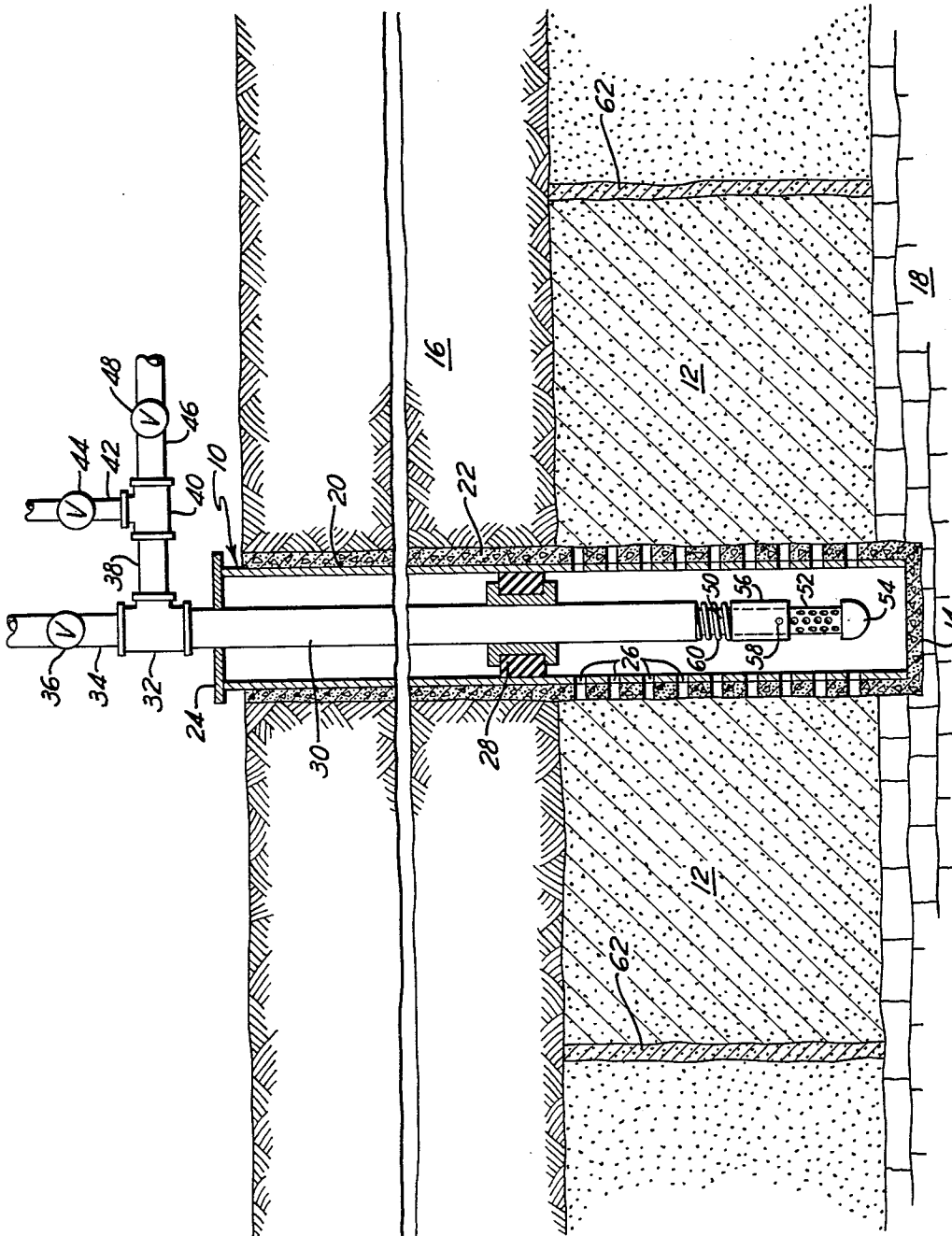


3,134,435

Filed Dec. 27, 1960



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METHOD FOR STABILIZING AN INCOMPETENT FORMATION**Malcolm R. J. Wyllie, Allison Park, Pa., assignor to Gulf Research & Development Company, Pittsburgh, Pa., a corporation of Delaware**

Filed Dec. 27, 1960, Ser. No. 78,706

7 Claims. (Cl. 166—25)

This invention relates to oil and gas wells and more particularly to the consolidation of sands surrounding the borehole of a gas or oil well.

Some underground formations from which gas or oil is produced do not have strength adequate to prevent erosion of the formation by the flow of the fluids through the formation to the well. Such friable or unconsolidated formations are frequently referred to as incompetent formations. During production of fluids into the well, the sands from the incompetent formation migrate into the well and may completely plug the well thereby making shutdowns for working over of the well necessary. If the formations are under high pressure and produce fluids at a high rate, the sands entrained with the fluids cause serious erosion of equipment in the well.

One method that has been used to reduce the difficulty with unconsolidated sands is to set a slotted liner in the producing formation and produce fluids through the slots of the liner. Another method that is employed frequently in combination with the setting of a slotted liner in the formation is to pack gravel around the liner to provide support for the incompetent formation. Displacing a liquid capable of setting to form a resin into the formation to provide a binder for the sand particles also has been proposed as a method of overcoming sanding problems.

The methods used to overcome the sanding problem have several disadvantages. The setting of liners and gravel packing around liners may require several round trips into the well which raises substantially the cost of the well completion. Ordinarily, liquids capable of setting to form resins are expensive and their use in large quantities to bind the formation for a substantial distance around the borehole of a well is costly. Moreover, frequently it is difficult to obtain a satisfactory bond between the resin-forming solution and the sand particles.

This invention resides in a method of stabilizing an incompetent formation by a reverse combustion process performed through a cokable liquid adjacent the borehole of a well to form a permeable coke structure bonding the sands of the formation. In the process of this invention a pyrophoric liquid is displaced from the borehole of a well radially outward into the formation and is followed by a cokable liquid, preferably a heavy crude oil or a residual oil. An oxygen-containing gas displaced down the borehole of a well fingers its way through the cokable liquid and upon contact with the pyrophoric material ignites the pyrophoric material which releases sufficient heat to initiate reverse combustion of the cokable liquid. The injection of the oxygen-containing gas is continued to continue reverse combustion to the vicinity of the borehole of the well. In a preferred embodiment of the apparatus for use in this invention, means are provided to stop the flow of oxygen-containing gas, and thereby stop the reverse combustion, in response to a rise in temperature in the borehole of a well.

The single figure of the drawing is a diagrammatic illustration, partially in vertical section, of a well in which the process of this invention is performed.

Referring to the drawing, a well indicated generally by reference numeral 10 is drilled through an incompetent formation 12 to a total depth 14. The incompetent oil-bearing formation 12 is between an overburden indicated

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by reference numeral 16 and an underlying rock formation 18.

Casing 20 is set in the borehole of the well through the incompetent formation 12 and cemented in place in accordance with conventional procedures to form a cement sheath 22 sealing the space between casing 20 and the borehole wall. The upper end of casing 20 is closed by suitable means such as a cap 24. The casing 20 and surrounding cement sheath 22 are perforated, as indicated by reference numeral 26, through the incompetent formation 12 to allow flow of fluids from the oil-bearing formation 12 into the well.

A packer 28 is set in the casing immediately above the upper boundary of the formation 12 and a tubing 30 is run through the packer. Tubing 30 extends upwardly through the cap 24 and is provided at its upper end with a T 32. An air supply line 34 having a valve 36 therein for control of air flow is connected to the top outlet of the T 32. The side outlet of the T 32 is connected to a line 38 having a T 40 connected therein. The upper outlet of the T 40 is connected to a supply line 42 for a pyrophoric material and has a valve connected therein for control of the introduction of the pyrophoric material into the T 40. The horizontal outlet of the T 40 is connected to a cokable liquid supply line 46 provided with a control valve 48.

In the preferred form of the apparatus illustrated in the drawing, a lower tubular extension 50 having a perforated section 52 extends from the lower end of the tubing 30. The extension 50 is closed at its lower end by cap 54. Slideably mounted on the extension is a sleeve 56. The tubing 30 is run into the well with the sleeve 56 held in an upper position above the perforated section 52 of extension 50 by a fusible pin 58. A compressed helical spring 60 surrounding the extension 50 urges the sleeve 56 downwardly. The tubing 30 may be provided at its lower end with a normally closed valve, not shown, which can be opened by the application of pressure on fluid in the tubing 30, to allow the tubing 30 to be filled with a liquid. If the pressure on the formation is high enough to cause the well to flow, a valve at the lower end of tubing 30 is not required.

In the operation of the process an inert liquid, preferably a hydrocarbon such as kerosene or crude oil, is introduced through supply line 46 into the tubing 30 to fill the tubing. Valves 48 and 36 are then closed, valve 44 opened, and a pyrophoric material displaced into the T 40 and through line 38 into tubing 30. A preferred pyrophoric material is triethylborane which may be displaced into the tubing 30 alone or dissolved in a hydrocarbon such as kerosene in concentrations above about 25% by volume of the triethylborane. Another suitable pyrophoric material is phosphorus dissolved in a solvent such as carbon disulfide.

After the desired amount of pyrophoric material is delivered into the tubing, it is displaced down the tubing and outwardly into the incompetent oil-bearing formation 12 by closing valve 44, opening valve 48 and pumping a cokable liquid into and down tubing 30. The cokable liquid must be one which can be oxidized in a reverse combustion process to release heat and will form coke when heated to the temperature attained in the reverse combustion. Preferred cokable liquids, because of their low cost and the ease with which they are coked, are heavy hydrocarbons such as heavy crude petroleum oils and reduced crude oils. A measured volume of the cokable oil is pumped into the system to displace the pyrophoric material the desired radial distance outwardly from the borehole of the well into the incompetent formation 12. The distance the pyrophoric material is displaced into the formation determines the location of the

initiation of the reverse combustion and, therefore, the radial extent of the stabilization of incompetent formations. A stabilized ring one foot in thickness is adequate to prevent migration of sands.

Valve 48 is closed after the cokable oil is displaced into tubing 30 and valve 36 opened. An oxygen-containing gas, preferably air, is displaced down tubing 30 and outwardly from the well into the incompetent oil-bearing formation 12. The higher permeability of formations to air than to viscous heavy crude oils or residual oils results in the air fingering its way through the cokable oil to the ring 62 of pyrophoric material. Upon contact with the air, the pyrophoric material ignites and releases heat of combustion adequate to raise the temperature of the formation to a level causing ignition of the cokable oil. Ignition of heavy crude oils will occur at temperatures as low as about 400° F.; hence, heating the formation to a high temperature with a pyrophoric material is not required. A volume of 150 cc. of triethylborane per square foot of peripheral area of the ring occupied by the triethylborane displaced into the formation is adequate.

Upon continued injection of air into the incompetent formation 12, the combustion front moves toward the well 20, countercurrent to the flow of air. The temperature of the combustion front can be controlled by the rate of injection of the air into the incompetent formation 12. It is preferred to control the rate of air injection to cause an air flux at the combustion front above about 40 standard cubic feet per square foot per hour to cause a temperature above about 750° F. to insure coking of oil in the formation at the combustion front. In the reverse combustion process there is always a deficiency of oxygen at the combustion front; hence, the coke formed as a result of the high temperature is not consumed but is left in the formation and forms a bonding medium of sufficient strength to prevent migration of sands during subsequent production of oil through the oil-bearing formation 12.

The in situ combustion continues with the continued injection of air until the combustion front approaches the well 20. When the combustion front reaches the well 20, the temperature within the well increases and causes the fusible pin 58 to soften whereupon the spring 60 forces the sleeve 56 downwardly over the perforated section 52 of the lower extension 50. The pressure within the tubing 30 rises sharply to indicate to the operator that the reverse combustion has been completed, whereupon the injection of air is stopped. Another control method for stopping the reverse combustion is to run tubing 30 into the well open-ended but with a thermocouple extending from its lower end. The thermocouple is suitably connected to indicating means at the well head whereby an increase in temperature in the borehole adjacent formation 12 is immediately indicated at the well head. Injection of the oxygen-containing gas is stopped when the indicating means registers a temperature increase.

The process of this invention provides a method of binding the particles of unconsolidated friable formations to form around the well a stabilized ring of sufficient strength to prevent migration of sand into the well. In contrast with the use of liquids which set to form resins, which have been suggested in processes of the prior art, the cokable liquid used for bonding the medium can be obtained at low cost. The deficiency of oxygen at the combustion front of the reverse combustion process prevents burning of the coke and destroying the bond

for the sand particles, yet the reverse combustion process does not cause the formation of soot, as does burning a fuel in a gaseous atmosphere with a deficiency of air, which would impair the impermeability of the formation. The high temperatures reached during the reverse combustion processes irreversibly dehydrates clays that may be present in the formation and thereby increase the permeability as well as the strength of a ring of the formation surrounding the well.

I claim:

1. A method for stabilizing an incompetent subterranean formation containing hydrocarbons penetrated by the borehole of a well comprising displacing a pyrophoric liquid from the borehole of a well into the incompetent formation, thereafter displacing a cokable liquid from the borehole of the well into the incompetent formation to move the pyrophoric liquid radially outward into the formation, thereafter displacing an oxygen-containing gas from the borehole of the well into the incompetent formation whereby the pyrophoric liquid is ignited upon contact with the oxygen-containing gas and reverse combustion of the cokable liquid is commenced continuing the injection of the oxygen-containing gas at a rate adapted to continue reverse combustion of the cokable liquid toward the borehole of the well whereby coke is formed to stabilize the incompetent formation.

2. A method for stabilizing an incompetent formation penetrated by the borehole of a well and containing hydrocarbons comprising displacing a pyrophoric liquid from the borehole of the well into the formation, thereafter displacing the pyrophoric liquid from the borehole of the well by displacing a cokable liquid down the well and into the formation, the displacement of the pyrophoric liquid into the formation being continued to form a ring of cokable liquid surrounding the borehole of the well in the incompetent formation surrounded by a ring of pyrophoric liquid, thereafter injecting an oxygen-containing gas into the well and displacing it from the borehole into the incompetent formation whereby the oxygen-containing gas ignites the pyrophoric liquid and commences reverse combustion of the cokable liquid, continuing the injection of the oxygen-containing gas at a rate adapted to move the combustion front through the formation toward the borehole of the well, and stopping the injection of the oxygen-containing gas into the well when the combustion front is adjacent the well.

3. A process as set forth in claim 1 in which a cokable liquid is a crude petroleum oil.

4. A process as set forth in claim 1 in which the cokable liquid is a reduced crude oil.

5. A process as set forth in claim 1 in which the pyrophoric liquid is triethylborane.

6. A process as set forth in claim 1 in which the pyrophoric liquid is triethylborane dissolved in a liquid hydrocarbon.

7. A process as set forth in claim 1 in which the pyrophoric liquid is phosphorus dissolved in carbon disulfide.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,134,435

May 26, 1964

Malcolm R. J. Wyllie

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 1, line 59, for "contitnued" read -- continued --;
column 4, line 22, after "commenced" insert a comma.

Signed and sealed this 27th day of October 1964.

(SEAL)

Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents