Dec. 25, 1962 J. B. COLBY ETAL 3,070,163

RECOMPLETION OF WELLS

Filed Aug. 5, 1960

FIG. 1.

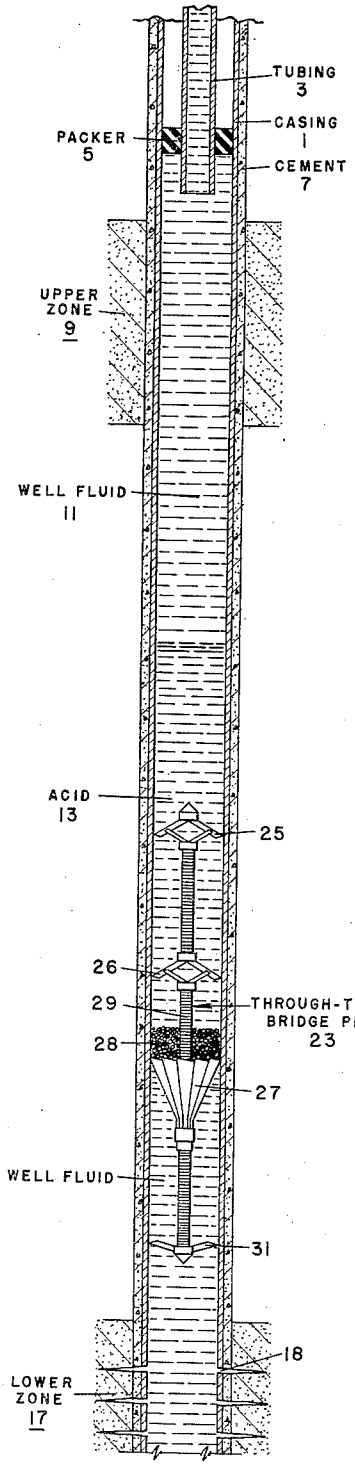


FIG. 2.

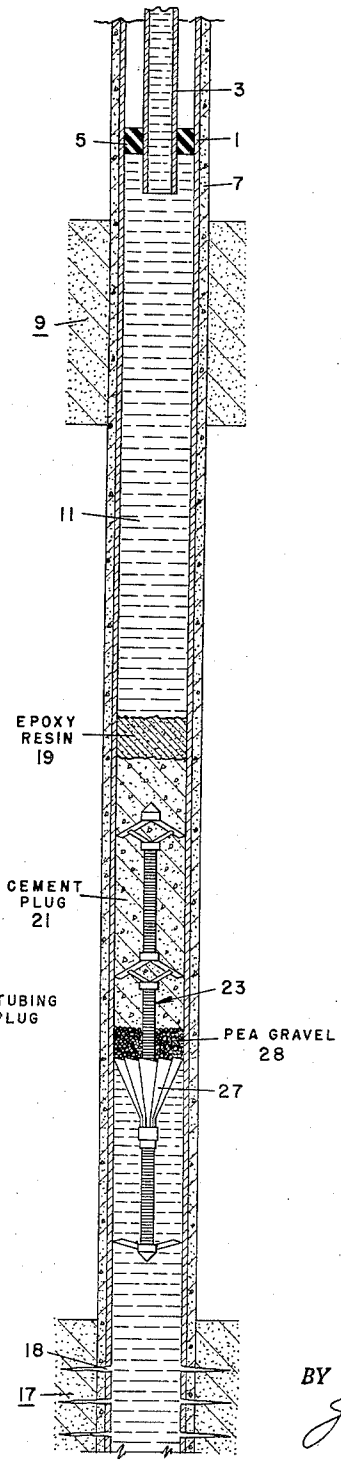
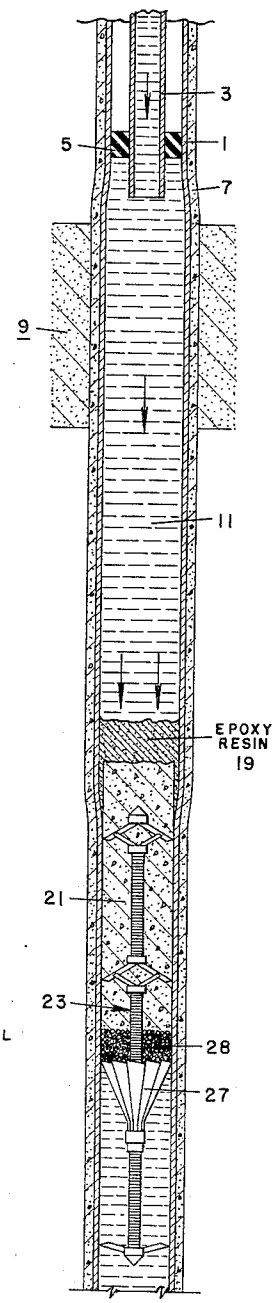


FIG. 3.



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RECOMPLETION OF WELLS

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8 Claims. (Cl. 166—33)

This invention relates generally to recompletions of wells, especially oil and gas wells, and more particularly to the isolation of fluid productive earth strata which are in fluid communication with the interior of a cased well bore.

After a hydrocarbon productive earth stratum has been produced for a more or less extended period of time, it is often found that the formation pressure has decreased to the point where it is no longer desirable to further produce the formation. Other factors, such as water intrusion into the well bore, may enter into the decision to no longer produce the formation. In such circumstances it may be found feasible to produce hydrocarbons from a second earth stratum that intersects the well bore at a higher level than the first earth stratum. It then becomes desirable to isolate the two strata so that the first stratum will not be produced simultaneously with the second stratum. It has been customary in the past to isolate strata by means of strong, heavy bridge plugs, the setting of which requires the production conduit, or tubing string, to be pulled from the well.

Recently, there have become available drillable bridge plugs that may be run through tubing strings on a wireline. The use of such apparatus is desirable because they are quite economical to use, they do not require special recompletion rigs at the surface for pulling tubing and similar operations, and they are particularly applicable to wells which have been previously set up for permanent type completion work. Bridge plugs all make use of a rather fragile stop device that may be expanded to the interior of the casing string after having been run out of the lower end of the tubing string. When the bridge plug has been set at the desired location in the casing string, a quantity of cement is dumped on top of the stop device and allowed to set. Usually a quantity of pea gravel is dumped ahead of the cement to provide a suitable base for the fluid cementitious mixture. Through-tubing bridge plugs are described in some detail in an article entitled "How Through-Tubing Bridge Plugs Work," by Robert W. Scott, at page 141 of the October 1959 issue of the periodical "World Oil."

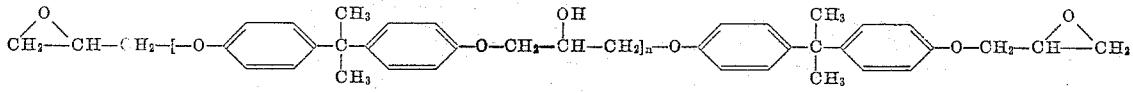
It is manifest that a large differential pressure will be exerted across the set plug inasmuch as the second upper productive zone will have a much larger formation pressure than the first, depleted lower zone. It has been found that such through-tubing bridge plugs often will become loosened as the result of the differential pressure thereacross and will move downwardly so that the two earth strata are brought into fluid communication.

In accordance with the teachings of the present invention, the bridge plug is run through the tubing and set in accordance with the teachings of the prior art. After the cement plug has been poured and has set up, a small quantity of epoxy resin mixed with an accelerator or hardener therefor is placed on top of the cement plug. The hydrostatic pressure exerted by the epoxy resin mixture on the cement plug is then increased to a pressure whereat the casing separates at least slightly from the cement plug. The separation should be such that a

quantity of the epoxy resin will flow between the cement plug and the casing. Contrary to what one would normally expect, the cement plug will not move downwardly through the casing until at least some epoxy resin is forced between the cementitious mixture and the casing. The pressure may then be released. After a sufficient time has elapsed for the epoxy resin to harden, it will be found that the plug is firmly bonded to the casing so that any differential pressure that may be exerted thereacross as a result of differences in the formation pressure of the strata in fluid communication with the bore of the casing will be insufficient to disrupt the bond between the cementitious mixture and the casing.

The invention will be further described with reference to FIGS. 1, 2, and 3 of the drawing wherein are depicted in schematic form a well installation and apparatus for use with the invention. The three figures illustrate various steps to be followed in the practice of the invention.

As indicated above, the present invention makes use of thermosetting type epoxy resins. Epoxy resins are diglycidal ethers of bisphenol A obtained by reaction between epichlorohydrin and bisphenol A using carefully controlled additions of caustic soda to control the pH neutralizing the hydrochloric acid formed in the reaction. The pH is maintained just below the end point of phenolphthalein, about 8 to 8.5. The epoxy resins suitable for use with the invention have at least two reactive epoxy groups in their molecule and are represented by the formula:



where n is an integer having a value of 1 or a greater number

Also used in connection with the invention are curing agents known as hardeners or accelerators for the thermosetting resin. The hardeners or accelerators have the property of catalyzing the hardening reaction of the thermosetting resin at low temperatures. The preferred epoxy resins may be cured or hardened in the following manner: (1) direct linkage between the epoxide groups by the use of tertiary amines of the general formula R_3N; (2) linkage of the epoxide groups with aryl or alkyl hydroxyls such as alcohols (ROH), with alcohols and tertiary amines ($ROH+R_3N$), or with di- or trihydric phenols $Ar(OH)_2$ or $Ar(OH)_3$; and (3) cross linkage with curing agents such as polyfunctional primary or secondary amines, (ROH) (NH_2) or $(ROH)_2(NH)$, with dibasic acids or anhydrides, $R(COOH)_2$ or $Ar(COOH)_2$, or with polyfunctional phenols plus curing agent ($Ar(OH)_2$+amine). In the sense used here, R indicates an alkyl group and Ar is the aryl group.

There are many amines, dibasic acids, and acid anhydrides that will serve as curing agents. Diethylene triamine, diethylamino propylamine, ethylene diamine, triethylene triamine, tridimethylaminomethylphenol, benzyldimethylamine, metaphenylenediamine, and 4,4′ methylene dianiline, are typical of the amine curing agents for eopxy resins. The acid anhydrides suitable for this purpose are illustrated by oxalic, phthalic, pyromellitic dianhydride and dodecenyl succinic anhydride. A preferred curing agent for use up to 160° F. is 2-ethyl hexoic acid salt of trimethylaminomethylphenol, in a concentration range of 6% to 16% by weight. A preferred curing agent for use in the range of temperatures from 160° F. to 250° F. is 30% by weight of diaminodiphenyl-sulfone along with 1 to 8% of borontrifluoride monoethylamine.

The well installation shown in each of FIGS. 1, 2, and 3 comprises a casing string 1 which has been run into a

borehole in the earth penetrating an upper hydrocarbon productive earth stratum 9 and a lower hydrocarbon productive earth stratum 17. One or more non-hydrocarbon productive earth strata may be found between the strata 9 and 17. The casing string is bonded to the sides of the borehole by a cement sheath 7 in the usual manner. A tubing string 3 is run into the casing so as to terminate above the upper zone 9 and a production packer 5 is used to isolate the lower portion of the casing bore below the lower end of the tubing string 3. The tubing string 3 may be set up for permanent type completion operations by including landing nipples therein (not shown). The casing is shown as having been perforated at perforations 18 so that the well bore is placed in fluid communication with lower zone 17.

In the practice of the invention it is essential that the portion of the interior of the casing string at the level at which the plug is to be set be free of corrosion brought on by oxidation. It is not usual for the interior of casings to be oxidized inasmuch as the usual type of casing corrosion is anaerobic in nature. However, where it is suspected that the interior of the casing string may be oxidized, such oxidation must be removed. This may be done by scraping the sides of the casing or, as illustrated in FIG. 1, by spotting a quantity 13 of inhibited acid at the level at which the plug is to be set. After a time interval sufficient for the acid to remove the oxidation, it may be circulated out of the casing bore in the usual manner, as by means of a tubing extension.

Either before or after the casing has been cleared of corrosion, a through-tubing bridge plug 23 is run through tubing 3 to the level at which the plug is to be set, as is shown in FIG. 1. The bridge plug 23 comprises a mandrel 29 supporting a stop member 27 here shown as a metal petal, or inverted umbrella, type of mechanism. The bridge plug further includes upper dogs 25, middle dogs 26, and lower dogs 31 which secure the bridge plug to the casing wall. The bridge plug is completely described in the aforecited article by Robert W. Scott and will not be further described herein. After the bridge plug 23 has been set, a quantity of pea gravel 28 is deposited on top of the metal petal stop member 27 by means of a dump bailer. After the casing has been cleared of corrosion above the pea gravel, a quantity 21 of fluid cement is dumped on top of the pea gravel and allowed to set.

A quantity of epoxy resin mixture 19 is thereupon deposited on top of the cement plug 21. The epoxy resin mixture comprises a quantity of epoxy resin mixed with one of the hardeners set forth above in a relative volume such that the epoxy resin mixture will be substantially unaffected by the hardener for a period of at least 30 minutes. This is for the purpose of insuring that the epoxy resin mixture will be sufficiently fluid for the operations to be described below. The preferable hardeners for the epoxy resin are set forth above.

By means of a pump (not shown) at the earth's surface, the hydrostatic pressure of the well fluid 11 on top of the epoxy resin mixture and cement plug 21 is increased to a pressure of at least 500 p.s.i. If the casing above the epoxy resin is liquid-free, the pressure can be increased by means of air compressors connected to tubing 3. Alternatively, the pressure can be increased by liquid pumps when the casing above the resin and below the packer 5 and tubing 3 is liquid filled. If the casing above the resin is free of liquid and it is desired to use liquid pumps to increase the pressure, it is manifest that liquid may be pumped through the tubing and deposited on top of the epoxy resin. At at least this pressure the walls of the casing below the packer 5 will bulge out as shown in FIG. 3. It is preferred that the diameter of the casing be increased by at least .005 inch. At an exerted pressure of at least 500 p.s.i, the casing diameter will increase by at least this amount. (The amount of bulging and the countour of bulge is exaggerated for illustrative purposes.) The epoxy resin mixture will flow down into the space or channels between the cement plug and the casing wall. The pressure may then be released and the epoxy resin allowed to harden. After a period of at least 24 hours, the casing may be perforated at the level of the upper zone 9 to bring the upper zone 9 into fluid communication with the casing bore.

If it is desired, the pressure exerted on the epoxy resin and the cement plug 21 may be just sufficient to start the cement plug moving downwardly. However, this is not necessary. It is postulated that the reason that the cement plug does not begin moving downwardly until the casing wall has expanded to permit at least some epoxy to flow between the plug and the casing wall is that the entire surface of the cement plug must be covered by fluid before the plug will begin to move. As long as any of the cement plug remains bonded to the casing wall, the cement plug will not move. Laboratory experiments conducted at the earth's surface have indicated that this is the mechanism responsive for plug movement.

Where cement plugs pre-exist in a casing, it may be desirable to follow the teachings of the invention in order to insure that there will be no movement of the cement plug in the casing. In those instances where it is believed that oxidation may exist on the casing wall, a quantity of inhibited acid may be spotted on the top of the cement plug and the hydraulic pressure increased to force the acid between the cement plug and the casing. In view of the fact that considerable acid movement is necessary for the acid to dissolve the cement, it will be found that the cement is virtually unaffected by the acid. The epoxy resin mixture may then be dumped on top of the remaining acid and the casing repressurized so that epoxy resin will flow between the cement plug and the casing as described above.

A considerable quantity of heat is released by the epoxy resin mixture while the epoxy resin is hardening. It would be suspected that the epoxy resin would contract upon cooling so as to break the bond with the casing wall. However, it has been found that this does not occur. It is postulated that the reason is that the cement plug is a very good heat absorber and that the heat generated by the reaction of the hardener with the epoxy resin is quickly absorbed by the cement plug. In the laboratory, plugs set in the manner described above have been found to resist differential pressure of 1500 pounds per square inch. Plugs of Portland cement placed and tested under the same laboratory conditions are found to resist differential pressures no exceeding 1000 pounds per square inch; hence, it is manifest that epoxy-bonded cement plugs represent a considerable and useful improvement in the art.

While the invention has been described for a well installation involving only two hydrocarbon productive earth strata, it is manifest that the invention is applicable to well installation wherein are involved three or more hydrocarbon productive earth strata and wherein two or more of the strata have become depleted.

The invention is not to be restricted to the specific structural details or arrangement of parts herein set forth, as various modifications thereof may be effected without departing from the spirit and scope of this invention.

What is claimed is:

1. In a well pipe string, a method of preventing migration of a cementitious plug located in the string between earth formations in fluid communication with the interior of the string, comprising: depositing on top of the cement plug a quantity of a liquid mixture of epoxy resin and a hardener therefor; increasing the hydrostatic pressure in the pipe string immediately above the plug to a pressure sufficient to expand the inner diameter of the pipe string to a diameter whereat at least some of the epoxy resin flows between the cement plug and the interior of the pipe string; releasing the hydrostatic pressure; and allowing the resin to harden.

2. In a well pipe string, a method of preventing migration of a cementitious plug located in the string between earth formations in fluid communication with the interior of the string, comprising: depositing on top of the cement plug a quantity of a liquid mixture of epoxy resin and a hardener therefor; increasing the hydrostatic pressure in the pipe string immediately above the plug to at least 500 pounds per square inch; releasing the hydrostatic pressure; and allowing the resin to harden.

3. In a well pipe string, a method of preventing migration of a cementitious plug located in the string between earth formations in fluid communication with the interior of the string, comprising: depositing on top of the cement plug a quantity of a liquid mixture of epoxy resin and a hardener therefor; increasing the hydrostatic pressure in the pipe string immediately above the plug to a pressure sufficient to increase the inner diameter of the pipe string at the cement plug by 0.005 inch; releasing the hydrostatic pressure; and allowing the resin to harden.

4. In a well pipe string, a method of preventing migration of a cementitious plug located in the pipe string between earth formations in fluid communication with the interior of the pipe string, comprising: depositing a quantity of an inhibited liquid acid on the cement plug; increasing the hydrostatic pressure in the pipe string immediately above the plug until the diameter of the pipe at the plug increases a sufficient amount to allow acid to flow between the pipe and the plug; releasing the hydrostatic pressure in the pipe string above the cement plug; depositing on top of the cement plug a quantity of a liquid mixture of epoxy resin and a hardener therefor; increasing the hydrostatic pressure in the pipe string immediately above the plug to a pressure sufficient to increase the inner diameter of the pipe string to a diameter whereat at least some of the epoxy resin flows between the cement plug and the interior of the pipe string; releasing the hydrostatic pressure; and allowing the resin to harden.

5. A method as in claim 4 wherein the increased hydrostatic pressure applied to the top of the cement plug is at least 500 p.s.i.

6. A method as in claim 4 wherein the pressure applied to the top of the cement plug is sufficient to increase the diameter of the pipe string at the cement plug by at least 0.005 inch.

7. In a well pipe string, a method of preventing migration of a cementitious plug located in the string between earth formations in fluid communication with the interior of the string, comprising: depositing on top of the cement plug a quantity of a liquid mixture of epoxy resin and a hardener therefor; increasing the hydrostatic pressure in the pipe string immediately above the plug to a pressure sufficient to expand the inner diameter of the pipe string to a diameter whereat at least some of the epoxy resin flows between the cement plug and the interior of the pipe string; and allowing the resin to harden.

8. In a well pipe string, a method of preventing migration of a cementitious plug located in the pipe string between earth formations in fluid communication with the interior of the pipe string, comprising: depositing a quantity of an inhibited liquid acid on the cement plug; increasing the hydrostatic pressure in the pipe string immediately above the plug until the diameter of the pipe at the plug increases a sufficient amount to allow acid to flow between the pipe and the plug; releasing the hydrostatic pressure in the pipe string above the cement plug; depositing on top of the cement plug a quantity of a liquid mixture of epoxy resin and a hardener therefor; increasing the hydrostatic pressure in the pipe string immediately above the plug to a pressure sufficient to increase the inner diameter of the pipe string to a diameter whereat at least some of the epoxy resin flows between the cement plug and the interior of the pipe string; and allowing the resin to harden.

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