

Sept. 28, 1965

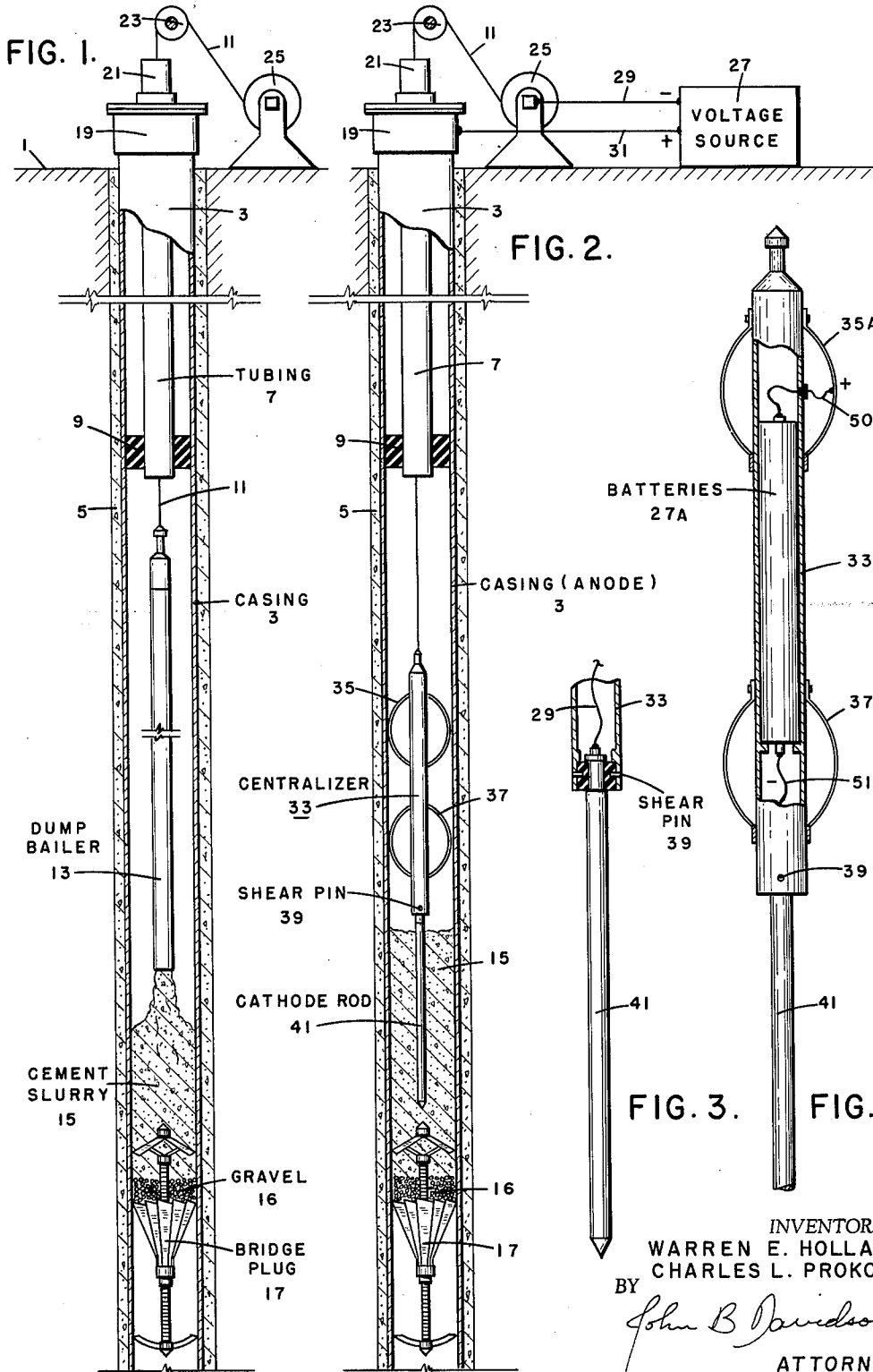
W. E. HOLLAND ETAL

3,208,521

RECOMPLETION OF WELLS

Filed Aug. 9, 1963

2 Sheets-Sheet 1



Sept. 28, 1965

W. E. HOLLAND ETAL
RECOMPLETION OF WELLS

3,208,521

Filed Aug. 9, 1963

2 Sheets-Sheet 2

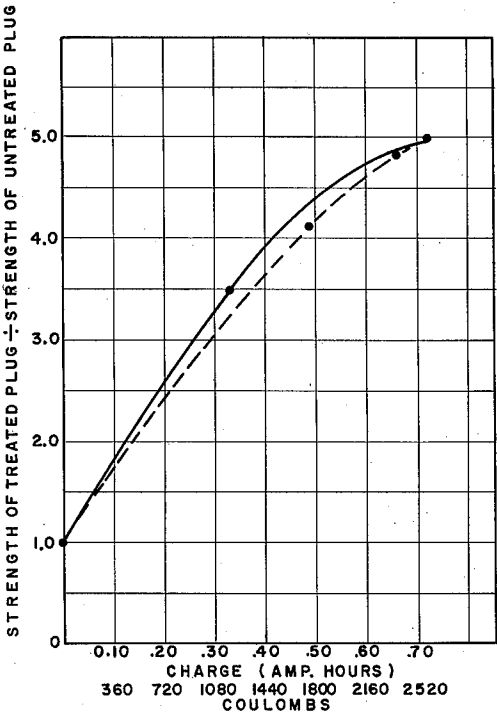


FIG. 6.

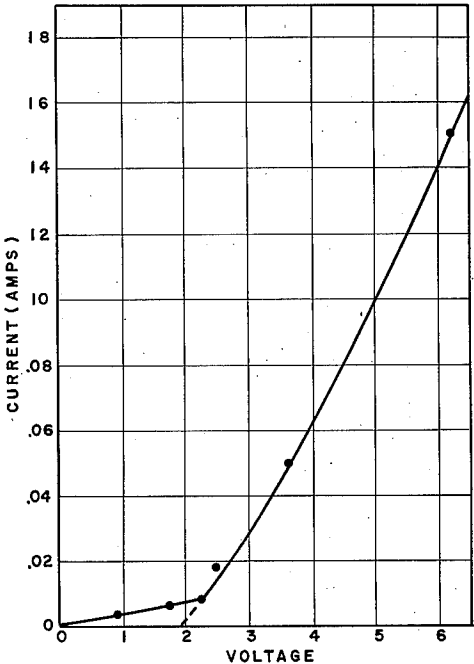


FIG. 7.

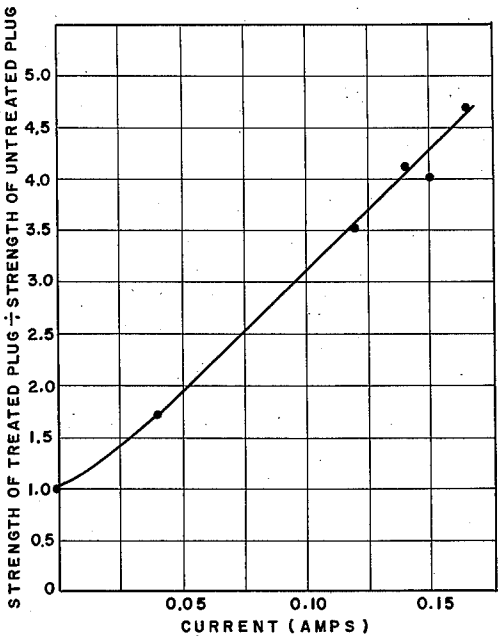


FIG. 5.

INVENTORS.
WARREN E. HOLLAND,
CHARLES L. PROKOP,
BY *John B. Davidson*
ATTORNEY.

1

3,208,521

RECOMPLETION OF WELLS

Warren E. Holland and Charles L. Prokop, Houston, Tex., assignors, by mesne assignments, to Esso Production Research Company, Houston, Tex., a corporation of Delaware

Filed Aug. 9, 1963, Ser. No. 301,051

4 Claims. (Cl. 166—25)

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.

In recent years, there have become available drillable bridge plugs that may be run through tubing strings on a wire line. 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 hardened, an electrical direct current is passed between the plug and the pipe. Preferably, this is accomplished by inserting an elongated conductive metal rod into the liquid cement before it has hardened. An electrical direct current potential is established between the rod and the pipe, with a positive electrical connection to the casing and a negative electrical connection to the rod, to cause direct electrical current to flow therebetween through the cement plug so that there is substantially uniform current density

2

through the vertical length of the plug. The bonding strength of the plug to the pipe will be found to have been tremendously increased.

Objects and features of the invention not apparent from the above discussion will become evident upon consideration of the following detailed description of the invention taken in connection with the accompanying drawing, wherein:

FIGS. 1 and 2 are schematic cross-sectional views of a well installation illustrating two of the steps in accordance with the invention;

FIG. 3 is a fragmentary view, partially in cross section, of a portion of the centralizer and shear pin apparatus shown in FIG. 2;

FIG. 4 is an elevational view, partially in cross section, of an alternate type of apparatus useful in performing the invention; and

FIGS. 5, 6 and 7 are graphs summarizing the results of experiments performed utilizing the technique of the invention.

With reference now to FIGS. 1 and 2, there is shown a well installation comprising a casing string 3 and a tubing string 7 co-extending from a well head 19 at the earth's surface 1. The casing 3 is bonded to the sides of a borehole by a cement sheath 5 in the usual manner and is in electrical contact with the earth strata. A production packer 9 is set near the lower end of the tubing string 7 to seal off the annular space between the tubing 7 and casing 3. A wire line lowering apparatus including reel 25 and a sheave 23 is provided at the earth's surface for lowering well tools through lubricator 21 down tubing string 7 into the well bore.

Initially, a through-tubing bridge plug 17 is lowered by means of the wire line apparatus into the well bore and is set at a predetermined level in the bore of casing string 3. The bridge plug 17 may be any of the types discussed in the article by Scott, supra. A quantity of pea gravel 16 and cement slurry 15 is dumped on top of the bridge plug 17 by means of a dump bailer 13 of conventional design, which is lowered into the well on wire line 11. The dump bailer 11 is quickly retracted from the well bore and an elongated conductive metal rod or cathode 41 is lowered into the well bore. As illustrated most perspicuously in FIG. 3, the rod 41 is connected to the lower end of an elongated centering device 33 having at least two retractable bow springs 35 and 37 for centering the device 33 substantially on the longitudinal axis of the casing string 3. It is manifest that the rod 41 will also be centered on the longitudinal axis of casing string 3. The rod 41 is connected to the centering device 33 by means of shear pin 39.

The wire line 11 on which the device 33 and rod 41 are lowered should include an electrical conductor 29 extending from power source 27 to rod 41 for conducting electrical current from the power source 27 to the conductive metal rod 41. The rod 41 is releasably mounted in and insulated from the lower end of the housing 33 as shown in FIG. 3. The electrical return to the power source 27 is through the casing or anode 3 and lead 31. Wire lines or cables having insulated electrical conductors are commercially available. A conventional logging cable such as is used for electric logs may be used for this purpose.

The metal rod 41 is inserted as far as possible into the cement slurry 15 without touching the bridge plug 17. When the rod 41 has been suitably positioned in the slurry 15, the power source 27 is energized and the current passing down conductor 29 to rod 41 is adjusted to between .006 and 2.0 amperes per square inch of contact between the casing 3 and the plug 15. Preferably, the current is maintained for a period of between .03 and 48 hours, the exact time depending on the magnitude of current flow; the minimum amount of electrical charge that should flow

during this time will be 50 coulombs per square inch of contact area between the casing 3 and the plug 15. As much as 400,000 coulombs per square inch of contact area will be found to be efficacious. The electrical current may be allowed to flow as set forth above after the cement has at least partially hardened, and has developed a substantial amount of compressive strength.

The cementitious mixture used in connection with the present invention may be a conventional Portland cement slurry, ASTM Type I cement. However, if desired, other cementitious mixtures such as any of the four other ASTM type cements, or gypsum-base cement may be used. Preferably, the casing string is a conventional iron pipe.

After the electrical current has been discontinued, the wire line is given a sharp jerk in order to break the shear pin 39. The device 33 is thereupon retracted from the well bore, and the casing string 3 may thereupon be perforated in the usual manner above the plug, and production operations begun from the new production horizon.

With reference now in FIG. 4, there is illustrated an apparatus for performing the method of the invention wherein the necessity for an electrical power source at the earth's surface is eliminated. The apparatus utilizes a cylindrical housing 33A for one or more batteries 27A. The batteries may be 1.5 volt flashlight batteries which may be connected in series, parallel, or series-parallel in accordance with the voltage and current requirements desired. The positive terminal of the batteries 27A is connected through an insulator in the housing 33A to upper bow spring 35A. The upper bow spring 35A preferably is electrically insulated from the housing 33A and is formed of a conductive metal. The lower bow spring 37A may be of similar construction if desired. A fishing neck is connected to the upper end of housing 33A. The lower negative terminal of the batteries 27A is electrically connected to rod 41; the rod 41 may be connected to the housing 33A in the same manner as illustrated in FIG. 3. If desired, a clock-timed switch may be inserted in the lead 51 between the lower terminal of the batteries 27A and the conductive rod 41 so that no current will flow for a predetermined period of time. This will conserve battery power until the apparatus has been lowered into the cement.

In practice, the apparatus described with respect to FIG. 4 is run in the well on an uninsulated, smooth wire line of the type normally used in running well instruments into wells. The device may be allowed to remain attached to the wire line. Electrical current will flow until the batteries are exhausted. At this time, the wire line may be given a sharp jerk so as to shear the shear pin 39 and the upper portion of the apparatus is recovered from the well. Alternatively, the wire line may be released from the fishing neck connected to the upper end of housing 33A and the apparatus may be permanently left in the well.

The efficacy of the technique described above was demonstrated in the laboratory in the following manner. A number of samples were prepared by pouring cement to a depth of 1½ inches in 6-inch long steel pipe nipples having an inside diameter of 1 inch. Shortly after pouring the cement for each plug, a number 8 copper wire was centered in each pipe and extended from the top of the pipe to ¼ inch from the bottom. Water was then poured over the cement slurry to prevent dehydration, and the plugs were cured for 22 hours at 150° F. A 12-volt battery was connected to the samples at the end of the curing time, with its positive terminal connected to the pipe and its negative terminal connected to the copper cathodes. The voltage was applied for 2 hours, and the current of each sample varied from .45 amperes at the beginning to .20 amperes at the end of the treatment period. The samples were tested by subjecting the plugs to hydrostatic pressure. All three plugs sustained the maximum test pressure of 3300 p.s.i. This compares to an average test pressure of 600 p.s.i. at failure for cement plugs of iden-

tical size and composition which were not treated electrically.

FIGS. 5, 6, and 7 summarize the results of a series of laboratory tests conducted wherein samples were prepared substantially in the manner described above. All of the tests were conducted in 1-inch test pipes. FIG. 5 shows the relative strengths of the plugs as compared with the strength of the untreated plug as a function of applied current in amperes. In each test the current was applied until 257 coulombs per square inch had passed. Assuming that the lower limit of strength is 1.5 times the strength of the untreated plug, it was found that the lower limit for the current should be about 0.01 amperes per square inch of pipe surface. It can be seen that a straight line relationship was attained throughout the test range after a slight curvature in the lowermost currents. It is known that the strength of the bond cannot increase indefinitely, but the test equipment used for determining the strength of the bond had a capacity of 3000 p.s.i. which was approached or reached during the tests.

In FIG. 6 is shown the relative strength of the plugs as a function of the quantity of electrical energy supplied. Assuming that the lower limit of satisfactory strength increase is 1.5 times the strength of the untreated plug, it was found that about 53 coulombs per square inch are required to obtain a satisfactory bond in accordance with the invention. The curvature at the upper end of the relationship indicates that the limit of strength appreciation possibly is being approached. However, the curvature is not sufficiently great to allow the prediction of the ultimate strength that may be reached. The highest value of one test (illustrated by the solid line), 2592 coulombs, is equal to 550 coulombs per square inch of plug area. One test (illustrated by the dashed line) was conducted in which a total of 2500 coulombs per square inch was passed, and it was found that the plug would not fail at 3300 p.s.i., the limit of the test equipment used. The last experiment was performed with 2000 p.s.i. hydrostatic pressure on the system, during which time the cement set and the plug was treated.

In FIG. 7 there is illustrated the current variation with voltage variation for one plug for the purpose of illustrating the resistance relationship of the cement. From the slope of the more or less straight part of the curve, the resistance can be seen to be about 27.6 ohms. The specific resistance can then be calculated using the equation:

$$R = (\rho/2\pi l) \ln \frac{R_1}{R_2}$$

where R is resistance, ρ is specific resistivity, R_1 is electrode radius, R_2 is the outside radius of the plug, and l is the length of the plug. The specific resistance was computed to be 146 ohm-inch. Also shown in FIG. 7 is the fact that the system of pipe-cement-electrode acts as a cell with the pipe cathodic to the electrode. The E.M.F. of the cell is shown to be 2.25 volts (the point of discontinuity on the curve, which is emphasized by the dashed line which shows the shape of the curve were the E.M.F. not present), and this much potential must be impressed before the current can be flowed in the reverse direction. The fact that the casing is cathodic to the electrode in the natural cell leads to an explanation of the reason that the process attains the surprising results noted above. The natural potential of the cell is overcome so that the casing becomes anodic, and electrolysis at the anode builds up reaction products that lock the cement plug in place. This hypothesis is strengthened by the observation that in every case where the plug strength was improved, the juncture between the pipe and the plug contained these reaction products.

The tests described above were all conducted in 1-inch I.D. pipe. In order to determine whether the same order of strength improvement could be obtained in field size pipes, tests were made in 18-inch lengths of casing having

5

4.9-inch inside diameter. These pipes were coated with SAE 20 motor lubricating oil to simulate conditions in a well. The cement was poured in the pipe and the electrode was arranged so that a 10-inch length of the cement was subjected to the current. A constant current of 6.5 amperes was used at 12 voltage for three hours in the electrical treatment. The cement-pipe area was 154 square inches, and the total current flow was 70,200 coulombs, or 455 coulombs per square inch of contact area. When this sample was tested it was found that the bottom half moved 1½ inches at 850 p.s.i. and that the pressure could be built up to 1500 p.s.i. with no further movement. Similar tests with untreated plugs indicated that they failed at about 200 p.s.i. These results showed the treatment improved the bond strength by at least the factor of 4, and after the small slippage of the bottom half, the bond strength was improved by the factor 7.5.

To determine the effectiveness of alternating current, a plug was prepared in 1-inch pipe in the manner described in the first example above. An alternating current of .33 amperes at 6.6 voltage A.C. was impressed on the plug for four hours. On testing, it was found that the plug resisted a pressure of 590 p.s.i., as compared to 600 p.s.i. for untreated plugs. From the results it can be seen that alternating current is ineffective in connection with the present invention.

Although the embodiments disclosed in the preceding specification are preferred, other modifications which do not depart from the scope of the broadest aspects of the invention will be apparent to those skilled in the art.

We claim:

1. A method of forming a plug in a well pipe comprising the following steps:

anchoring a support member at a given level in the pipe;

depositing a quantity of a liquid cementitious mixture on the support member;

inserting a conductive metal rod in the cementitious mixture so that the rod extends substantially through the cementitious mixture and is substantially centrally located on the longitudinal axis of the well pipe;

after the cementitious mixture has hardened for a period of at least 2 hours, passing an electrical direct current from the well pipe to the rod through the hardened cementitious mixture until there has passed at least 50 coulombs of electricity per square inch of contact between the pipe and the cementitious mixture.

6

2. The method of claim 1 wherein the pipe is made of iron and the cementitious mixture is formed from a Portland-type cement.

3. A method of forming a plug in a well pipe comprising the following steps:

anchoring a support member at a given level in the pipe;

depositing a quantity of a liquid cementitious mixture on the support member;

inserting a conductive metal rod in the cementitious mixture so that the rod extends substantially through the cementitious mixture and is substantially centrally located on the longitudinal axis of the well pipe; and

after at least partial hardening of the cementitious mixture, passing an electrical direct current from the well pipe to the rod through the hardened cementitious mixture having a substantially uniform current density, until there has passed at least 50 coulombs per square inch of contact between the well pipe and the cementitious mixture.

4. A method of forming a plug in a well pipe comprising the following steps;

anchoring a support member at a given level in the pipe;

depositing a quantity of a liquid cementitious mixture on the support member;

contacting the mixture with an electrode; and after the cementitious mixture has at least partially hardened, passing an electrical direct current from the well pipe through the hardened cement mixture to the electrode, said current having a substantially uniform current density, until there has passed at least 50 coulombs per square inch of contact between the well pipe and the cementitious mixture.

References Cited by the Examiner

UNITED STATES PATENTS

828,976	8/06	Schneider	204—130
1,977,756	10/34	Dutoit	204—130
2,118,669	5/38	Grebe	166—65 XR
2,302,913	11/42	Reimers	138—97
3,064,734	11/62	Toelke.	

FOREIGN PATENTS

496,518	11/38	Great Britain.
---------	-------	----------------

CHARLES E. O'CONNELL, *Primary Examiner.*