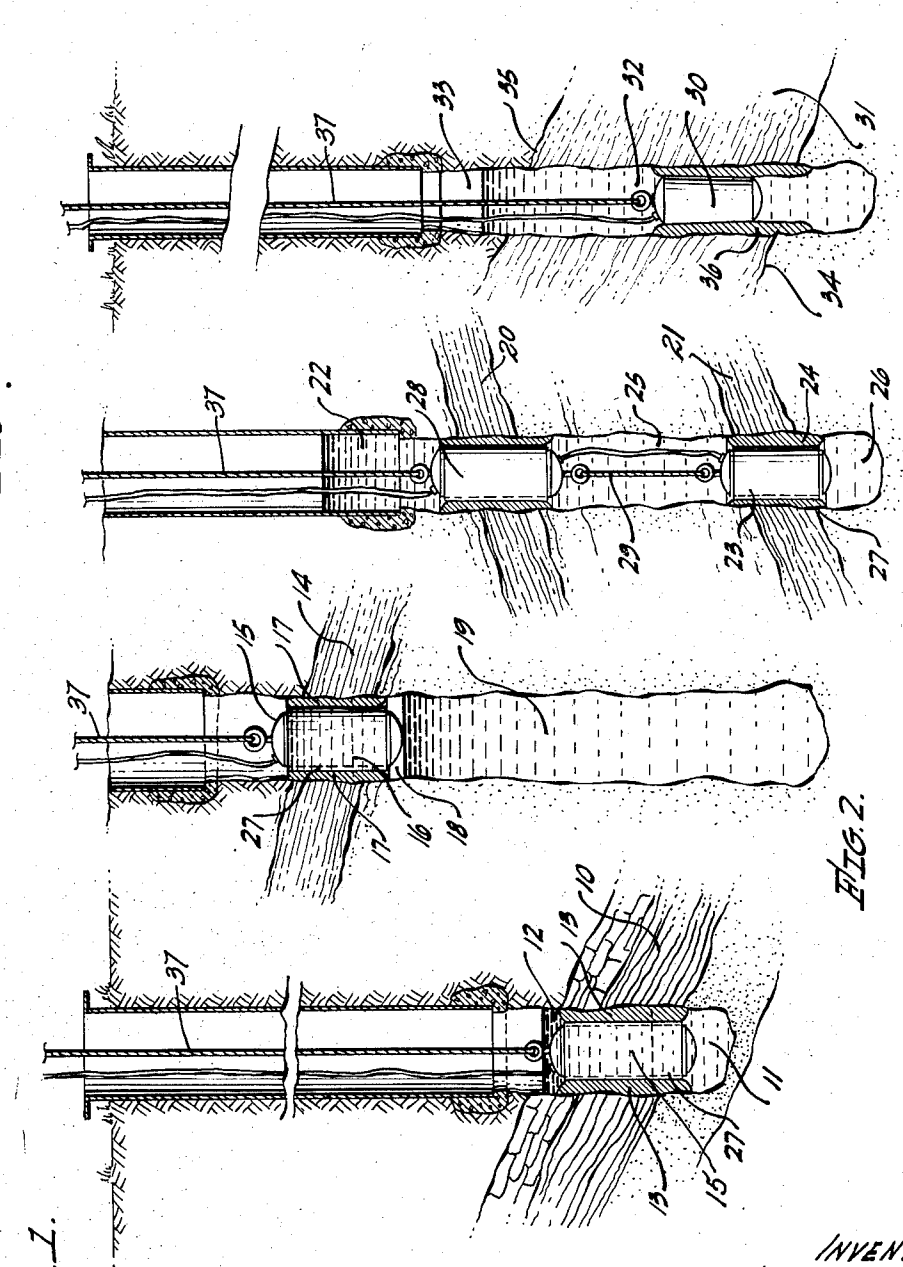
Sept. 2, 1952 B. P. KANTZER 2,609,052

TREATMENT OF WELL BORES

Filed March 12, 1948



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Patented Sept. 2, 1952

2,609,052

UNITED STATES PATENT OFFICE

2,609,052

TREATMENT OF WELL BORES

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Application March 12, 1948, Serial No. 14,630

7 Claims. (Cl. 166—22)

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This invention relates to methods for treating well bores to prevent the inflow of fluids from fluid-containing formations and/or the loss of fluids employed in drilling the well into other parts of the formation. This invention relates in particular to methods for the selective plugging or sealing porous strata encountered in well boring including wells that are drilled to produce oil, gas, water, brine, sulfur, and other materials.

In the drilling of wells, particularly oil and gas wells, the rotary drilling method is usually employed in which a hollow drill pipe or drill stem with a rotary bit attached to the lower end is used. This drill stem is extended downwardly through the borehole and rotated as the bit is pressed against the working face at the bottom of the hole to grind away the formation and thereby deepen the bore. During this rotary drilling operation a fluid commonly called a drilling fluid is circulated through the hole by passing downwardly through the hollow drill stem, through the bit past the working face, and then upwardly to the surface through the annular space between the drill stem and the face of the well bore. This drilling fluid assists in drilling by lubricating and cooling the drill bit, suspending cuttings broken away from the formation at the working face by the action of the rotating bit and carrying them out of the hole, plastering the face of the borehole with a thin impervious layer of solid material to inhibit the flow of fluid into or out of the formation, applying a hydrostatic pressure to the formation to counterbalance the pressure of liquids or gases occurring in some of the penetrating strata and fulfills other requirements.

Various strata are penetrated by the borehole, some of which are hard and impermeable, some are soft and easily drilled, some are highly porous containing considerable quantities of water or other fluids which are sometimes present under considerable pressure, some are cavernous into which the drilling fluid tends to accumulate and for all practical drilling purposes is therefore lost, and some tend to swell and cave-in or slough material off into the borehole thereby greatly hampering the drilling operations. Some of the porous structures containing high pressure water, brine, or gas reduce the ease of drilling by diluting the drilling fluid and destroying its desirable properties, coagulating the clay often used in the drilling fluid, gas cutting the drilling fluid and reducing its specific gravity and making it foam. These are some of

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the deleterious effects which may be encountered while drilling through high pressure strata. In drilling through cavernous structures or low pressure permeable strata, quantities of the drilling fluid may be lost flowing into such structures under the hydrostatic pressure of the fluid.

It is therefore highly desirable to effect some kind of a seal between the borehole and such cavernous or porous strata or strata which tends to cave in, slough off or otherwise hinder drilling operations. In field practice such situations have been to some degree improved by inserting a casing comprising a steel tube downwardly through the borehole as far as a region of impermeable strata at which point the casing is landed and a cement slurry is forced into the annular space between the casing and the borehole face. Such a procedure does not positively insure effective sealing of the porous or cavernous strata and considerable lengths of time are required for the cement slurry to harden before shut-off tests can be run. Difficulties are sometimes encountered in forcing the cement slurry into the annular space since the elevated well temperatures accelerate the setting or hardening of the cement. Thus considerable quantities of cement may remain and harden in the borehole proper and are therefore required to be drilled out prior to resuming the actual deepening of the well bore proper. Furthermore, such cement shut-offs are adversely effected by brines and acids and other corrosive materials frequently used in wells. In some cases cement seals thus introduced must be completely replaced due to the disintegrating action of corrosive materials. It is to a method for performing well bore sealing operations that this invention is directed in which an effective, impermeable and long lasting seal may be effected between well bores and porous strata.

It is an object of this invention to provide a method for sealing permeable underground strata encountered during the drilling of oil, gas, water or brine wells into the earth.

Another object of this invention is to provide a method of sealing porous strata in which the sealing compound is inert to brines, acids, oil or other materials present in such wells.

A further object of this invention is to prevent the loss of drilling fluids employed in drilling wells by the rotary drilling method by sealing thief sands or similar porous strata with a solid impervious sealing material.

An additional object of this invention is to provide a method for the selective plugging of

porous strata encountered in well drilling by means of a thermo-setting plastic material introduced into the well bore, which upon heating is transformed into a strong and impervious solid.

It is a more particular object of this invention to provide a method for selective plugging of porous strata which comprises the introduction of a liquid resin-forming material into the well bore which when subjected to localized heating opposite the porous strata causes the solidification of a portion of the resin-forming liquid which effectively seals the porous strata without the solidification of the remaining resin-forming liquid. The remaining unsolidified resin-forming liquid is thereafter removed from the hole by bailing, pumping, or other convenient means.

Other objects and advantages of the invention will become apparent to those skilled in the art as the description thereof proceeds.

Briefly, the present invention comprises the selective plugging of portions of a well bore by the selective solidification of a resin-forming liquid opposite porous strata which are desirably sealed or otherwise shut off without the solidification of the entire quantity of resin-forming liquid thus introduced. Resin-forming liquids having solidification temperatures above those encountered in the well are preferred. By the method of this invention, only a portion of the resin-forming liquid is solidified leaving the remaining portion of the liquid standing in the hole opposite strata which need not be sealed unsolidified as a liquid. This liquid is subsequently removed from the hole. This method results in an effective selective plugging of particular strata encountered during drilling which is porous or cavernous, or for other reasons must be sealed.

In this specification the solidification temperature is taken to mean the temperature to which a resin-forming liquid must be heated to solidify in about 1.0 hours.

The resin-forming liquids which are preferably employed in the practice of the present invention are those liquids which form thermo-setting plastic solids upon the application of heat. These liquids are generally organic in nature and interact with themselves or other constituents through polymerization or condensation reactions or form addition products resulting in a hard insoluble, infusible solid mass under the influence of heating. The solid materials resulting are hard and inert to chemical action of water, brine, oil and acids, or other materials generally used in oil well drilling practice. The plastic solid resulting is infusible and further heating will not cause softening or plastic flow so that the material is tenaciously held in position and is difficultly removed. Excessively high temperatures, far above those encountered in formations penetrated by oil wells, will cause thermal decomposition of the plastic with a liberation of carbon and decomposition gases, but the solid material will not melt or flow. This distinguishes the thermo-setting plastic materials from a class of plastics designated thermo-plastics solids. These latter, the thermo-plastic solids, may be formed from liquids under the action of moderate heating. However, continued heating to higher temperatures causes a softening of the plastic to a degree at which it will flow. These types of thermo-plastic solids may be employed in the improved strata sealing method of this invention, provided the well temperatures at the particular depth are not sufficient to cause softening of the solid or prevent solidification.

Resin-forming liquids which form solids of the thermo-setting type are preferred for use in this invention. This class includes the phenol formaldehyde type, cresol formaldehyde, phenol furfural, melamine formaldehyde, urea formaldehyde, allyl esters, and similar types of plastics which are formable from liquid monomers or other liquids. Those containing formaldehyde are particularly well suited. The poly-ester solids formed from the interaction of unsaturated polyhydroxy alcohols with unsaturated di- or polycarboxylic acids may be applied. Plastic polymers formed from styrene and other liquid hydrocarbon monomers may be used in the practice of this invention. Resin-forming liquids containing formaldehyde are well suited to the practice of this invention.

The use of plastics in oil well practice has been previously proposed whereby such plastics were introduced to seal porous strata through which the borehole had penetrated. These proposed methods, however, involve the use of resin-forming liquids which act much the same as the cement slurries employed in conventional sealing practice in that the solidification reaction was initiated at the surface and the slowly solidifying resin-forming liquids were of necessity hurriedly introduced into the well before excessive solidification had resulted. In some instances, it was necessary to apply high pressures as in cementing practice to force these solidifying materials into the porous formation. Furthermore, the previously proposed method involving the complete solidification of the entire quantity of resin-forming liquid thus introduced, thus requiring excessive quantities of these liquids.

The present invention, however, involves the selective solidification of a portion of the resin-forming liquids and the subsequent removal of the remaining unsolidified portion when sufficient solidification has resulted in effective sealing of a predetermined strata.

The present invention further is more effective than the previously proposed methods since resin-forming liquids employed in this invention are selected to have solidification points which are sufficiently in excess of the temperatures of the ambient strata to be sealed that no substantial solidification will occur without the application of localized heating of the resin-forming liquid adjacent to the strata to be sealed. In this manner the minimum amount of sealing material is thus introduced and used to fulfill the requirements for which they are introduced.

The procedures of this invention will be more clearly understood by reference to the accompanying drawings, Figures 1, 2, 3, and 4, in which the several modifications of selective plugging operations of this invention, described more fully below, are shown.

The presence of a strata in a well bore which must be sealed is readily apparent and its position within the well bore either with reference to the bottom of the hole or the surface of the ground is readily determinable by any one of a number of well known logging methods. If it is desirable to seal a porous strata 10 which is immediately above the bottom of the well bore as shown in Figure 1, the method of this invention may readily be applied and the excess unsolidified resin-forming liquid 11 and 12 bailed from above the solid material 13. However, porous strata which must be sealed are frequently far from the bottom or far from the top of the well bore as shown in Figure 2 and the methods of the present

invention are more easily applied than those proposed previously. In this event the resin-forming liquid may be introduced into the well so that it stands to a level just above that of the strata 14 to be sealed. A heating unit 15 is subsequently immersed into the resin-forming liquid 16 opposite the porous strata and localized heating is applied to the liquid between the heater and the strata which causes the solidification of a sufficient portion 17 of the resin-forming liquid about the heater to effectively seal the porous strata. Heating is then discontinued and the heating unit is then pulled free of the solidified resin. The remaining nonsolidified resin-forming liquid 18 is bailed or pumped from the well. If insufficient resin-forming liquid is available, a weighted drilling mud or other fluid 19 may be employed to fill the lower part of the hole.

In another instance as shown in Figure 3, if it is desirable to shut off or otherwise seal two adjacent porous strata 20 and 21, a procedure similar to that described above may be employed in which the well is bailed to a depth just below that of the porous strata and a sufficient quantity of resin-forming liquid 22 introduced to a level somewhat above the upper porous strata 20. The heating unit 23 is then inserted into the well and centrally located in the bore opposite the lowest of the porous strata 21. The application of heat causes the solidification of the resin-forming liquid 24 immediately adjacent to the heater and the effective sealing of the lower porous strata 21 without the solidification of the remaining resin-forming liquid 25 above or 26 below the heater 23. The heater is subsequently pulled free, possibly out of a drillable or plastic shell 27, and raised to a position opposite the upper porous strata 20 at which position the heating is resumed and this strata is likewise sealed. The heating is then discontinued, the heating unit withdrawn from the well, and the remaining quantity of unsolidified resin-forming liquid 25, 26 and 22 is bailed out. This material is preferably saved for reuse in subsequent sealing operations.

A modification of the last described sealing operation, also shown in Figure 3, may be effected in which a pair of heating units 23 and 28 is employed. The heaters may be separated by means of a suspension rod 29 of a sufficient length so that when these heaters are lowered into the well each is immediately adjacent to a strata to be sealed and the sealing operation of both strata may be accomplished simultaneously. This modification may obviously be extended to a multiplicity of strata, the relative location of which may easily be determined by the conventional logging methods.

The heating units employed in the practice of this invention may involve the application of electrical heat of resin-forming liquid immediately adjacent to a porous strata in the well bore. The application of high frequency alternating current energy, the frequency of which lies within the radio-frequency range, may be employed if desired. With the application of radiated radio-frequency energy the higher frequencies are preferred such as in the range of from 1000 kilocycles to 500 megacycles, and is preferably employed using highly directive radiators so as to concentrate the radiating energy in a horizontal plane perpendicular to the borehole. Other methods of effecting localized heating are applicable such as the introduction of heaters employing exothermic chemical reactions which are readily controllable from the surface of the earth by electrical or other means. Electrical resistance heaters are preferred, units having capacities from less than about 1 kilowatt to as high as 50 kilowatts or higher depending on the quantity of liquid to be solidified and the rapidity with which the operation is desirably effected.

The important consideration in selecting the heating means is that of obtaining localized heating to solidify the resin-forming liquid immediately adjacent to the heater without solidifying substantial quantities beyond the upper and lower extremities of the formation to be sealed. The dimensions of the heater are also important and heating units should be selected which have diameters between about 50% and 95% of the diameter of the borehole at the position of the strata to be sealed. Thus, only a very small amount of the resin-forming liquid need be solidified to form a good seal. Heating units may be selected having lengths which approximate the depth of the porous strata or as is shown in Figure 4 heaters such as 30 having lengths substantially less than the depth of the porous strata 31 may be used in which case the heat is continuously applied as to the resin-forming liquid 32 while the heater 30 is slowly moved upwardly through the well bore 33 so that during the passage of the heater from the lower extremity 34 of the porous formation 31 to its upper extremity 35 a substantially complete solidification 36 of the resin-forming liquid 32 over that interval has been effected. The application of heat is then discontinued and the heater withdrawn from the hole or moved to another position in the bore.

To facilitate removal of the heater from the solidified resin, a plastic jacket 27 shown in Figures 1, 2 and 3 may be provided on the outside surface of the heater from which the heater may be pulled by means of the suspending cable 37 shown in the four figures. The heat passes radially through the jacket to effect solidification and the jacket is then left in the hole.

The "phenol-formaldehyde" class of thermosetting plastics previously listed as the resin-forming liquids are particularly well suited to the practice of this invention since the temperature to which the liquid must be heated to effect solidification is very readily changed to meet temperature conditions encountered in a given well bore. The molar ratio of phenol to formaldehyde, for example, may be changed from the optimum of about 1.0 to a higher or lower value in order to increase the solidification temperature. It is preferable to compound a resin-forming liquid which has a solidification temperature at least 20° F. above and preferably more than about 40° F. above the ambient formation temperature in the bore. The heater is then employed to heat a portion of the liquid from the well temperature to the solidification temperature, an increase of from 20° F. to over 40° F. Since the formation temperature increases with increasing depth of the hole, about 20° F. per 1,000 feet of depth, the solidification temperature of the resin-forming liquid employed at a 10,000 foot depth, for example, should preferably be between about 270° F. and about 300° F. Preferably the solidification temperature of the liquid compounded for use in this invention is at least equal to:

$$T°F = 70 + 20D$$

where D is the depth in thousands of feet at which the thermosetting resin is to be employed.

It is sometimes desirable in particular instances

to seal porous formations containing high pressure fluids such as gas or water. In some instances a weighted drilling mud generally employed in drilling such formations is bailed to a level just below the lower extremity of the high pressure porous strata and the high pressure fluid, if it is water, is allowed to enter the well and rise to a static level. The resin-forming liquid is then introduced through a tube into the interface between the weighted fluid and the water to form a third layer of immiscible resin-forming liquid immediately opposite the porous formation. In such cases the density of the resin-forming liquid is preferably greater than that of water and less than that of the weighted drilling fluid at the bottom of the hole. Following the introduction of the resin-forming liquid into the proper position, the tube through which it was introduced is withdrawn and the heating unit is inserted to introduce a sufficient quantity of heat to effect solidification of a portion of the liquid which effectively seals the porous formation. The heater is then withdrawn, and the well is then bailed of water following which drilling may continue unhampered. Should the high pressure porous strata contain gas, a similar procedure may be adapted involving the insertion of water into the well under pressure to effectively block the flow of gas from the strata into the well following which the resin-forming liquid may be introduced, as described, immediately above and solidified.

As an example of the use of the method of this invention, the following examples are given:

Example I

The sealing of a porous thief sand through which considerable quantities of drilling mud were being lost was accomplished by removing the drill string from the hole and bailing the drill mud from the hole to a level just below that of the porous strata. The well bore was 8 inches in diameter and the porous sand to be sealed was 7 feet in thickness and situated at a depth of about 5,000 feet. The amount of resin-forming material required to raise the level of liquid from below the lower extremity of the porous sand to above the upper extremity thereof was determined to be about 25 gallons. The resin-forming liquid employed in this instance was a phenol-formaldehyde composition having a 1 hour solidification temperature of about 210° F. It had been previously heated in the presence of caustic soda to a temperature of about 170° F. and cooled. The resulting material was then mixed at normal temperatures with a solidification catalyst containing alcohol and hydrogn chloride and introduced into the well. An electrical heating unit having a diameter of about 6.5 inches and a length of 6.5 feet was introduced into the well to a position opposite that of the porous strata, and 2½ kw. of electrical heat applied for a period of 1½ hours to heat and maintain the portion of the liquid to be solidified at a temperature of about 210° F. This resulted in effective solidification of the resin-forming liquid and after cessation of heating the heater was withdrawn and an effective shut-off of the porous strata was indicated by no drop in mud liquid when the hole was filled prior to beginning the subsequent drilling operations. A small quantity of the plastic formed opposite the porous sand was drilled out without adversely affecting the seal in any way after which the drill string was run into the bottom of the hole and further drilling continued.

Any of the phenol-formaldehyde class of thermosetting resins may be employed in exactly the same manner as indicated above and including urea-formaldehyde, cresol-formaldehyde, and the like.

Example II

In a shallow well, a permeable strata may be sealed by using monomeric styrene as the resin-forming liquid. To seal a 15-foot thick strata at a depth of about 8500 feet, 65 gallons of styrene are introduced into an 8-inch borehole forming an immiscible layer opposite the strata to be sealed on the drilling mud remaining in the hole. An electrical heating unit having a diameter of 6.5 inches and a length of 4.0 feet is lowered to the lower extremity of the permeable strata and 0.75 kw. of heat applied to raise that portion of the resin-forming liquid to be solidified to a temperature of about 275° F. The heater is slowly lifted to the upper extremity of the strata causing solidification of the resin-forming liquid opposite the thief sand to occur. The heat is next shut off and the unit removed. Bailing the well effects recovery of unsolidified styrene and an effective seal is formed. Natural gas pressure may be applied to the well to prevent vaporization of the resin-forming liquid during heating.

The above examples show the selective plugging action of the methods of this invention which is applicable to the selective sealing of permeable strata during drilling or after completion of an oil, gas, water or brine well. These methods may also be applied to sealing leaky casing or to repairing cement seals which have failed through corrosion or other causes. The selective resin-sealing method of this invention may also be applied to the mechanical strengthening of certain formations penetrated by the borehole.

A particular embodiment of the present invention has been hereinabove described in considerable detail by way of illustration. It should be understood that various other modifications and adaptations thereof may be made by those skilled in this particular art without departing from the spirit and scope of this invention as set forth in the appended claims.

I claim:

1. A method for sealing permeable underground strata which comprises positioning a thermo-setting resin-forming liquid around a heater positioned opposite the strata to be sealed, applying heat selectively to the annular portion of said liquid between said heater and said strata to cause solidification to form an infusible and insoluble solid without substantial heating of those portions of said liquid above and below said heater, stopping the application of heat, and removing the heater and the remaining portion of unsolidified liquid.

2. A method according to claim 1 in which said resin-forming liquid comprises one containing formaldehyde.

3. A method according to claim 1 wherein said thermo-setting resin comprises a liquid containing a phenol and formaldehyde.

4. A method according to claim 1 in which said thermo-setting resin comprises melamine formaldehyde.

5. A method according to claim 1 wherein said resin-forming liquid contains unsaturated poly-

hydroxy alcohols and unsaturated di- and polycarboxylic acids.

6. A method according to claim 1 wherein said resin-forming liquid is compounded to have a one hour solidification temperature at least 20° F. in excess of the ambient temperature of the formation at the depth at which it is employed.

7. A method according to claim 1 in combination with the step of moving said heater from one extremity of said strata to the other thereby applying heat selectively and solidifying successive parts of said annular portion of said thermo-setting resin-forming liquid.

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