Dec. 7, 1954 C. R. FAST 2,696,260

APPARATUS FOR COMPLETING WELLS

Original Filed June 13, 1950

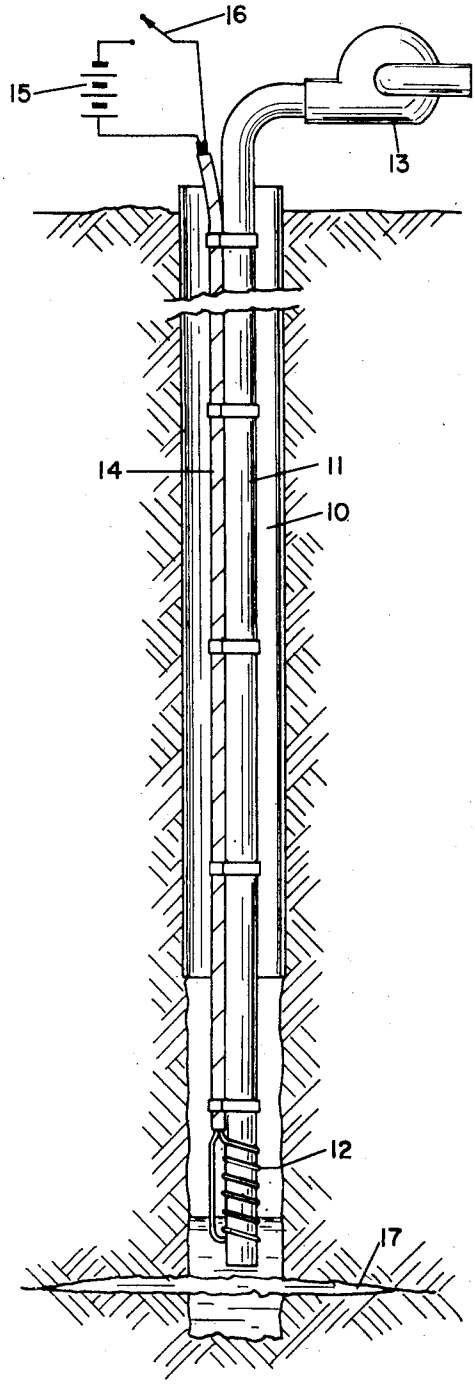


FIG. 1

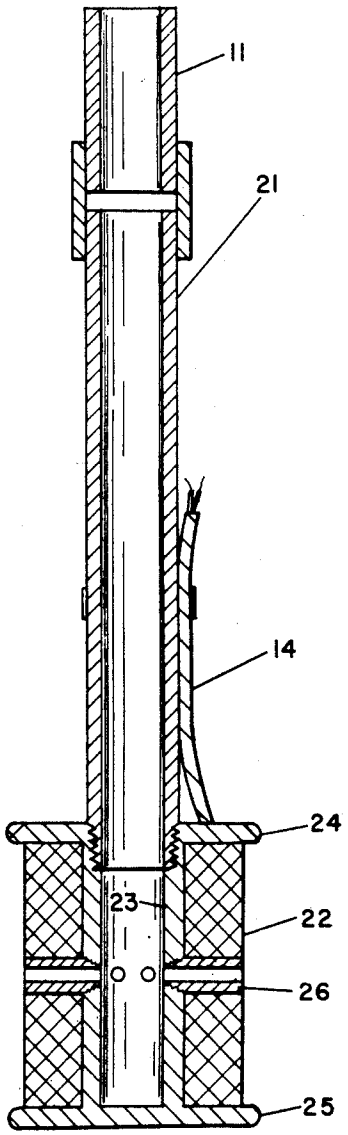


FIG. 2

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United States Patent Office 2,696,260
Patented Dec. 7, 1954

2,696,260

APPARATUS FOR COMPLETING WELLS

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Original application June 13, 1950, Serial No. 167,809. Divided and this application May 7, 1951, Serial No. 225,026

7 Claims. (Cl. 166—65)

This invention pertains to an improved apparatus for treating wells. More particularly, this invention pertains to an improvement in apparatus for producing a fracture in a formation penetrated by a well to facilitate the recovery of fluids therefrom. This is a division of my copending application Serial Number 167,809, filed June 13, 1950.

Various methods have been proposed for increasing the productivity of water, oil, and gas wells; for example, nitroglycerin has been detonated in a well in some cases either to enlarge the well diameter or to fracture the formations immediately adjacent the well. Acid has been injected into wells and into formations, particularly calcareous formations, for the same purpose. Wells have also been drilled laterally from a central bore for the purpose of increasing the productivity and drainage area of wells. Fractures have also been produced in formations by the application of a high hydrostatic pressure in the well, whereby the permeability of a formation adjacent a well and the drainage area around the well are increased.

It is an object of this invention to provide an improved well apparatus. A further object of this invention is to provide an improved apparatus for solidifying a magnetic fluid in a well. These and other objects of this invention will become more apparent from the following description in which reference will be made to the accompanying drawings. In these drawings:

Figure 1 is a diagrammatic representation of a cross section of a well showing apparatus employed to fracture a formation in accordance with this invention; and

Figure 2 is a cross sectional view of one type of apparatus used in isolating a formation to be fractured and at the same time changing the properties of the fracturing fluid so that it has a more desirable filtrate rate.

The present improvement in the process of fracturing formations consists, in brief, of temporarily isolating a formation by magnetic means and injecting a fracturing liquid into it under a pressure great enough to produce a fracture. As indicated in Figure 1, a well **10** may be equipped with a tubing **11**, which has associated therewith, at approximately the depth of the formation which is to be fractured, a magnet **12**. At the surface a high-pressure, high-volume pump **13** is connected to the upper end of the tubing, and the suction line of this pump may be, in turn, connected to a source of magnetic fluid or other fracturing liquid. In case the magnet **12** is, as in the preferred embodiment, an electromagnet, leads **14** from the surface to the electromagnet may be attached as by clips to the tubing **11**. At the surface these leads are connected across a battery **15** or other suitable supply of electric energy. Obviously, this power source may be a DC or an AC generator, or any supply which will produce a magnetic field about an electromagnetic coil, as is well known in the art. A switch **16** may also be incorporated in the circuit of the electromagnetic coil.

A fluid which has the property of stiffening when it is in a magnetic field is prepared at the surface. This fluid, herein referred to as a magnetic fluid, is defined as a fluid containing finely divided magnetic materials wherein the frictional forces between the magnetic materials can be controlled by the application of a magnetic field. Besides this magnetic material, the magnetic fluid contains a suspending liquid. In the case where an oil-producing formation is to be fractured, the liquid component of the magnetic fluid is preferably oily. Any mineral oil, fish oil, animal oil, or other oil-miscible liquid can be used.

A trixotropic oil—i. e., an oil which has appreciable gel strength—is sometimes desirable to prevent the magnetic particles from settling when the fluid is in a quiescent unmagnetized state. Addition of a small amount of a highly polar surface-active agent, such as oleic acid, to the oil produces this effect. Crude oil from the formation itself can be used; but, in general, I have found that more viscous oils are generally desirable. Whereas crude oil may have a viscosity of from about 1 to about 10 centipoises, a viscosity in the range of from about 20 to about 200 or more centipoises has been found to be more desirable. A lubricating oil, a steam cylinder oil, or the like are examples of the preferred oily liquid for the magnetic fluid. In case of a water-producing or water-disposal formation, an aqueous base liquid is preferred. I incorporate in this liquid the finely divided, highly permeable magnetic solid. Suitable solids are hydrogen-reduced iron, hypo-eutectoid steels, eutectic steels, hyper-eutectoid steels, carbonyl iron, carbon steels, and magnetic iron oxide. Other finely divided materials which exhibit magnetic properties, for example, cobalt, nickel, and molybdenum powders, may be used in place of the iron powders; but, in general, these particles have a lower permeability than the iron powders and, therefore, are less desirable.

The magnetic material is ground to a particle size of between about ½ and about 60 microns, or more. In general, the larger particle sizes are preferred, since the permeability of a mixture of this material with a liquid is directly proportional to the particle size. The limiting factor on maximum particle size is the ability to maintain the particles in suspension—the more viscous the suspending liquid, the larger the particles it will suspend.

The ratio of magnetic material to liquid may be varied over a substantial range. I have found, however, that the ratio of from about 1 to about 10 parts magnetic material to 1 part of liquid by weight produces satisfactory fracturing liquids. Since the permeability of the fluid increases with an increase in the ratio of magnetic material to liquid, higher ratios of magnetic material to liquid are preferred. Pumpability of the magnetic fluid fracturing liquid appears to be the only factor which limits the maximum ratio of magnetic material to liquid, and pumpability of the fluid depends, among other things, upon the pump, the particle size, the liquid, and the like. There appears to be no minimum concentration of magnetic material in the oil except that at low concentrations the permeability of the magnetic fluid becomes relatively low, thereby decreasing the viscosity of the fluid under a magnetic field. A ratio of magnetic material to liquid of greater than about 5 is preferred. The permeability of the magnetic fluid is generally the element which determines the minimum concentration of magnetic material in the liquid. A permeability of greater than about 3 in CGS units is considered operable in most cases; however, I prefer a permeability of greater than about 5. The ratio of magnetic material to liquid must, therefore, be adjusted for each set of circumstances.

These particles are incorporated in the liquid by any suitable means; for example, by stirring or by a jet-type mixer. This magnetic fluid is displaced into the well **10** through tubing **11** by pump **13**. The fluid, due to the inclusion of the iron particles, is generally more dense than the well fluid and, therefore, unless otherwise constrained, appears to displace the well fluids upwardly in the well. The magnetic fluid may be placed in the well before the magnet **12** is lowered into the well or, in the case of an electromagnet, before it is energized. I have found it generally desirable, however, to energize the magnet before the magnetic fluid is introduced into the well to prevent loss of the magnetic fluid to the formations. Where the core of an electromagnet is highly permeable, as, for example, where the core is constructed of tubular magnetic material such as iron, the magnetic field within the core is substantially zero and, therefore, the flow of the magnetic material through the core is not materially retarded by the magnet. Near the end of the magnetic coil, which is preferably placed near the end of the tubing, the magnetic field has its maximum intensity. Therefore, the frictional forces between the magnetic particles, i. e., the

viscosity of the magnetic fluid, are greatest around the end of the tubing. The extreme viscosity or set of the magnetic fluid prevents the magnetic fluid from flowing upwardly around the tubing—the viscous fluid in this region functioning like a packer between the tubing and the well wall. This high viscosity is generally adequate to prevent flow of the magnetic fluid into the annulus between the tubing and the well wall, but a packer may occasionally be set in this area to advantage. Magnetic fluid issuing from the tubing is by comparison substantially less viscous than the magnetic fluid between the tubing and the well walls. Accordingly, this magnetic fluid flows into and fills the confined zone in the well below the end of the tubing. The zone may be limited at the lower end by the bottom of the well, by a packer, a plug, another magnet, or other means well known in this art. The magnetic field from magnet **12** extends into this fluid and thereby increases its viscosity. This increased viscosity prevents the magnetic fluid from penetrating the pores of the formation.

If injection of the fluid is continued after the confined zone becomes filled with viscous magnetic fluid, hydraulic pressure on the fluid rises until the strength of the formation is overcome and a fracture **17** results. The hydraulic pressure in the confined zone necessary to produce a fracture has been found to vary in wells 2000 ft. or more in depth from about 0.7 to about 1 lb. per foot of well depth. This pressure of the magnetic fluid required to fracture a formation is hereinafter referred to as the formation-breakdown pressure. It is generally recognized by an observation of the pressure in the tubing. After the confined zone becomes filled with magnetic fluid, the pressure rise, assuming a volume of two or more barrels per minute, is roughly proportional to the volume of the fluid injected into the well. After the formation fractures, the pressure rise ceases to be proportional to the volume of the fluid injected into the well. In fact, in many cases, the pressure may decrease sharply when the formation fractures, even though there is no decrease in the fluid injection rate. The pressure at which this change in the slope of a pressure-versus-volume curve occurs is the formation-breakdown pressure. After the formation fractures, the magnetic fluid enters, and the fracture may be extended a substantial distance from the well by continuing to pump fluid into the well. It appears that whereas the field strength of the magnet and the viscosity of the magnetic fluid are greatest adjacent the end of the magnet, the viscosity of the magnetic fluid may be maintained reasonably high for a substantial distance into the formation due to the relatively high permeability of the magnetic fluid in comparison to the permeability of the rocks. That is, the flux lines of the magnet appear to be concentrated in and to follow the lens of magnetic material and to return to the tubing from great distances through the rocks. Obviously, the viscosity of the fluid gradually decreases with distance from the magnet as the field decreases. Once a fracture has been initiated, the pressure required to extend it is generally reduced, and, therefore, the fracture appears to be extended several feet into the rocks, even though the flux density, and therefore the viscosity of the fluid, is much less at this distance than in the well at the end of the tubing. The flux density is generally maintained as high as possible in the well consistent with sound engineering design of permanent or electromagnets so that the fracture can be extended to great distances.

Any amount of magnetic fluid may be injected into the fracture. For example, from about 100 to about 5000 gallons or more may be used, but it appears that a 1000-gallon treatment on the average is about the most desirable, considering cost and results.

After the magnetic fluid has been injected into the fracture to the desired distance, the electromagnet may be deenergized by opening switch **16**. Any magnetic fluid in the well **10** and fracture **17** then becomes less viscous, and the liquid filters into the formations surrounding the fracture, allowing the granular particles to be deposited in the fracture. These particles then support the overlying formations and maintain a highly fluid-permeable path from the formation into the well. The liquid, being in the preferred embodiment miscible with the liquid in the formation, may then be produced with the well fluid, as by flowing, swabbing, or pumping the well.

The magnetic field may be produced, as indicated above, by a number of types of apparatus. In the case of an electromagnet, the magnetic field may be produced or discontinued at will, whereas in the case of a permanent magnet the magnetic field is continuous. An electromagnet is, therefore, preferred, since the removal of the tubing may be facilitated by de-energizing the magnet and reducing the viscosity of the magnetic fluid before removing the tubing. Even though the viscosity of the magnetic fluid is not reduced, however, the tubing and magnet may be removed from the well by the application of a suitable force. It appears that, upon the application of a magnetic field, the magnetic particles in a magnetic fluid come into contact with each other, producing a quasi rigid or very viscous connection between the magnet and the well walls, thereby tending to freeze the tubing in the well. The magnet can, however, be moved through this viscous mass if sufficient force is applied.

An alternative type of apparatus particularly adapted to fracturing formations is shown in Figure 2. In this embodiment, a non-magnetic tubular sub **21** is attached to the lower end of tubing **11**. Where alternating current is applied to the magnetic coil **22** at the lower end of the sub, the sub is preferably constructed of a strong non-conducting material such as plastic. However, where direct current is used to energize the coil, the sub may be constructed of brass or other non-magnetic metals. While the non-magnetic sub is obviously desirable, it is not necessary since it merely assists in concentrating the magnetic field from the coil. Coil **22** is connected via leads **14** to a source of electrical energy as above described. The coil is wound on a magnetic core **23** having upper annular pole piece **24** and lower annular pole piece **25**. These pole pieces and the core may be laminated to advantage where AC power is used. Lower pole piece **25** may be a circular plate which closes the lower end of the tubing. A number of fluid outlets **26** are provided around the periphery of the tubular core and extending through the coil. These conduits may be threaded into the tubular core as indicated. They are preferably constructed of a non-magnetic material such as brass so as not to affect the magnetic field produced by the coil.

In operation, this apparatus is lowered into the well, as described in connection with the embodiment shown in Figure 1, the coil is energized, and the magnetic fluid is injected through tubing **11**, non-magnetic sub **21**, and fluid outlets **26** into the well. Since the magnetic field is substantially stronger adjacent the pole pieces, the magnetic fluid in the well contiguous to these pole pieces has a viscosity much greater than the viscosity of the magnetic fluid in the intermediate zone. In fact, the magnetic fluid adjacent the pole pieces may, with high field strength, be made practically rigid, thereby preventing the escape of magnetic fluid into the well above and below the pole pieces. Being rigid not only prevents flow of the magnetic fluid into the well above and below the coil but also prevents it from flowing into the formation at these points. Since the reluctance of the flux path through the formation is roughly equal to the reluctance of an air path, the magnetic field between the pole pieces extends out from the coil through the formation, and the flux density decreases as a function of the radial distance from the pole pieces. The depth of penetration of the flux path into the formation is dependent on the ampere-turns in the coil and on the length of the coil. Accordingly, high power input to the coil and a long coil, e. g., from about 5 to 20 ft. or more, are preferred. The viscosity of the magnetic fluid around the coil is thus increased to some extent so that it does not readily penetrate the permeable formations—the magnetic fluid in effect having a low filtrate rate due to the forces between the magnetic particles in the liquid. Since the magnetic fluid in the zone surrounding the energized coil has a low filtrate rate, it will not be lost into the formations when a high pressure is applied. This permits the formation-breakdown pressure to be built up so that a fracture can be initiated.

The magnetic field from coil **22** extends into the formation a substantial distance, the strength of this field, and accordingly the viscosity of the magnetic fluid, being a function of the distance. In some cases, the magnetic fluid enters the formation in a lens which is much closer to one pole piece than to the other so that the highly permeable pole piece is, in effect, extended out into the formation by the relatively high permeability magnetic fluid. The magnetic flux leaving one pole piece would then extend in a concentrated path through this lens out into the formation and would return to the other pole piece through the high reluctance formation. Thus, by

the embodiment illustrated in Figure 2, an intermediate zone in a well can be isolated from the remainder of the well and the adjacent formation can be fractured by a simplified process, i. e., a process which avoids the use of packers, plugs, or the like that are always difficult to set in a well and obtain a seal.

In some cases, it is desirable to use spaced magnets to isolate a zone rather than to isolate a zone between the pole pieces of a single magnet as above described. In such case the magnetic field in the isolated zone between the magnets is subject to better control, and therefore the viscosity of the magnetic fluid in this zone is more easily controlled.

This invention has been described above with particular reference to fracturing a formation with the magnetic fluid which thus performs two functions—both isolating and fracturing a formation. In some cases, it is desirable to use different fluids for the two functions. That is, I have found it particularly advantageous to first surround the magnet or magnets with magnetic fluid, stiffen this fluid at points in the well by energizing the magnet or magnets, and then inject a fracturing liquid into the zone isolated by the magnetic fluid. The second or fracturing liquid may be any liquid which has a very low filtrate rate and which will thus not filter into the formations too fast to permit the formation-breakdown pressure to develop. Suitable fracturing liquids such as oily materials containing bodying agents, for example, the metallic soaps, particularly the hydroxy aluminum soaps, are described in the copending application of Joseph B. Clark, Serial Number 29,932, filed May 28, 1948.

It will thus be apparent that this invention is subject to a wide variety of embodiments and should, therefore, not be limited by the above-mentioned apparatus or by the particular magnetic fluids described. Instead this invention should be limited in scope only by the appended claims.

I claim:

1. A well packer for isolating a section of a well including, a tubing string in said well, a highly permeable tubular electromagnetic core attached to the lower end of said tubing string, spaced annular pole pieces on said core, an electromagnetic coil on said core between said pole pieces, means to energize said electromagnetic coil, a radial fluid passage through said coil at a zone of relatively low flux density between said pole pieces, and a plugging liquid containing a powdered magnetic material, said plugging liquid being disposed around said pole pieces and being substantially solidified when said electromagnetic coil is energized.

2. A well packer for isolating a section of a well comprising a well tubing in said well, a highly permeable tubular electromagnetic core in said well, spaced annular pole pieces on said core, an electromagnetic coil on said core between said pole pieces, means to energize said electromagnetic coil, a radial fluid passage through said coil, and non-magnetic tubular means to connect said core to said tubing.

3. A well packer for isolating a section of a well containing a well tubing including a highly permeable tubular electromagnetic core at the lower end of said well tubing, spaced annular pole pieces on said core, a source of electric energy at the surface, an electromagnetic coil on said core between said pole pieces, conductor means connecting said source of electric energy to said coil, and a radial fluid passage through said coil at a zone of relatively low flux density.

4. A well packer comprising an electromagnet disposed in a well, means to energize said electromagnet, a magnetic fluid comprising a liquid containing a magnetic material, said electromagnet being surrounded in said well by said magnetic fluid, and said magnetic fluid being capable of substantial consolidation in said well by said electromagnet, and a well tubing connected to said electromagnet and extending between said electromagnet and the surface.

5. A well packer according to claim 4 wherein said means includes a source of electrical energy at the surface and an electrical conductor connected between said source and said electromagnet.

6. A well packer for isolating a section of a well including a tubing string in said well, a tubular magnetic core disposed at the lower end of said tubing string, spaced annular pole pieces on said magnet, an insulated coil on said core between said pole pieces, and a radial fluid passage through said coil between said pole pieces.

7. An apparatus for isolating and treating a section of a well including a tubing string extending into said well, a highly permeable tubular electromagnetic core at the lower end of said tubing, spaced annular pole pieces on said core, an electromagnetic coil on said core between said pole pieces, a source of electrical energy at the surface, electrical conductor means affixed to said well tubing and connected between said source and said coil, a radial fluid passage through said coil between said pole pieces, a magnetic fluid comprising a liquid containing a powdered magnetic material surrounding said pole pieces, and means to inject fluid down said tubing and through said fluid passage for treating said section of said well.

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