July 28, 1959 T. A. KIBBY 2,896,718

METHOD OF AND APPARATUS FOR COMPLETING WELLS

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Fig. 1.

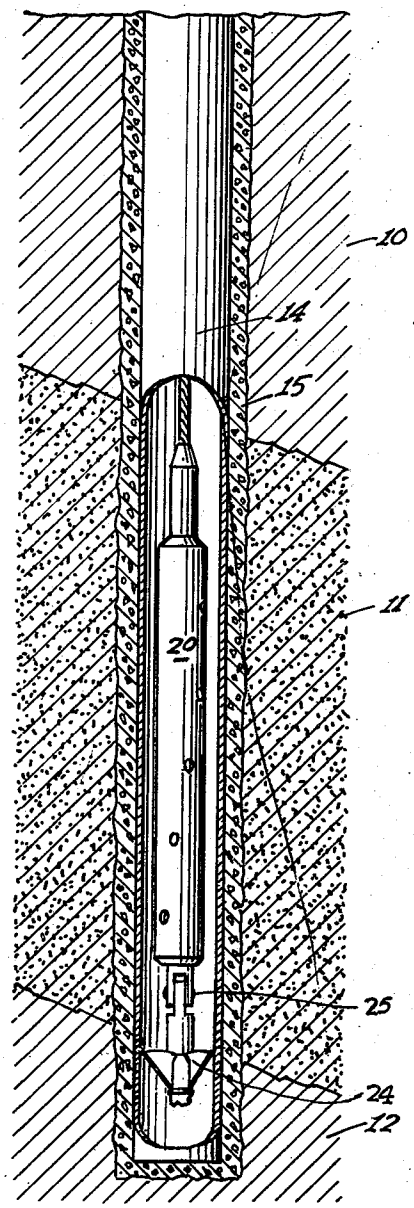
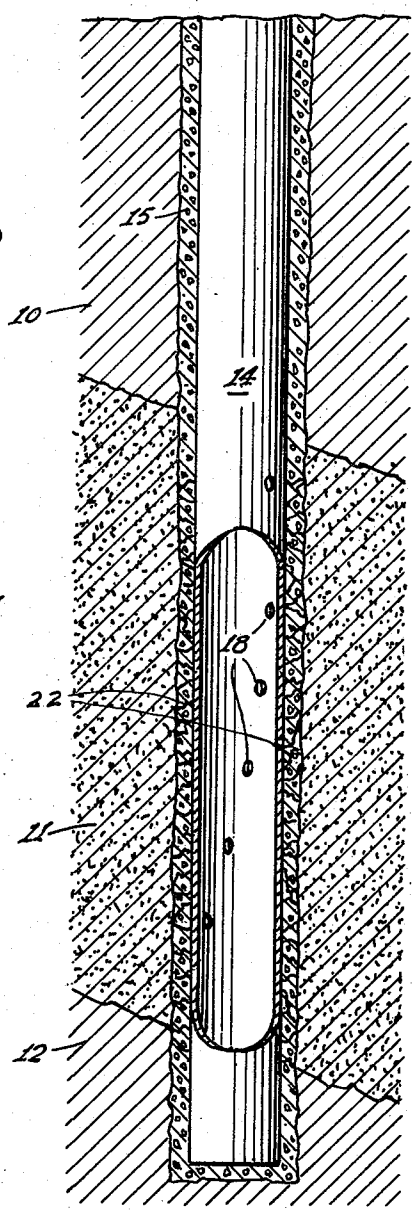


Fig. 2.



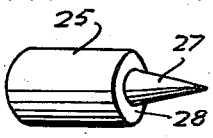


Fig. 3.

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METHOD OF AND APPARATUS FOR COMPLETING WELLS

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3 Claims. (Cl. 166—35)

This invention relates to a method of and apparatus for completing wells, and more particularly, to a method and apparatus for producing a well structure in a producing formation which comprises a perforated tubing and a surrounding cement sheath having a system of small fractures therein. This application is a continuation-in-part of my copending patent application, Serial No. 450,630, filed August 18, 1954, now abandoned.

The method of the invention is especially useful for completing wells in poorly consolidated formations where sand control is a problem. In producing oil, gas, or other fluids from poorly consolidated formations such as unconsolidated sands, it is desired to avoid the production of sand with the fluids in order to prevent costly shutdown, due to clogging of the well bores, and to avoid damage to pumps and other well equipment. A number of procedures for sand control have been employed including the use of various types of strainers in the producing formation; for example, wire-wrapped slotted pipes, gravel packs, and the like. The prior art means for sand control have not been entirely satisfactory. Abrasion caused by sand particles enlarges the openings in the wire-wrapped slotted pipe and allows the production of substantial quantities of sand which usually accumulates in the well bore, stopping production and necessitating an expensive clean-out process. The openings in the pipe are also subject to clogging by sand with resulting decrease in production. Gravel packs are also subject to clogging. This is due to the fact that it is difficult to place the gravel in the well without forming voids in some places in the pack. Such voids allows shifting of the gravel during production and consequent movement of sand which clogs fluid passages in the pack and stops or reduces production.

In completing wells in consolidated producing formations certain problems can occur when conventional methods of completing wells by gun perforation are practiced. Recent evidence indicates that when bullets or shaped charges from a gun or jet perforator are fired through a well casing and into a consolidated producing formation, drilling mud or other solids may be forced into the perforations. When this occurs the productivity of the formation is poor. Tests show that the mud or other finely divided solids can form a solid plug in the perforation. In some instances mud is even forced into the pores of the consolidated formation and reduces permeability. The method of the present invention can avoid these problems of low productivity which can occur in wells completed in consolidated formations by gun perforation.

The patent applications of Abraham J. Teplitz, Serial Number 424,862, filed April 22, 1954, now abandoned, and Serial Number 501,063, filed April 13, 1955, describe a new method of completing wells which makes possible the production of oil from unconsolidated oil sands without the production of substantial quantities of sand and which, when applied to the completion of wells in consolidated formations, avoids the problems of mud plugging which are encountered in well completion by conventional gun perforating. In the new method a tubular casing is installed in the well in the producing formation and a cement sheath is formed about the casing in the annular space between the casing and the formation wall. Small fractures or cracks are formed in the cement sheath which communicate with openings in the tubular casing. These fractures allow oil to filter through the cement sheath and enter the perforations in the well casing while sand is excluded and the surrounding unconsolidated formation is supported by the cement sheath. The present invention is directed to an improved specific embodiment of the method for completing a well described in said Teplitz applications and to a novel apparatus for use in the method.

The concept of the present invention in general comprises installing in a well drilled in a producing formation a tubular casing coaxial with the borehole, forming a cementitious sheath in the annular space between the casing and the walls of the producing formation, and firing from within the casing and into the wall of said casing a bullet having a substantially conical point and an annular shoulder at the base of its point for arresting the forward movement of the bullet after the point has pierced the wall of the tubular casing. The result of this operation is that the casing is perforated and small fractures are formed in the cement sheath which provide passsages for fluids from the producing formation into the perforations in the casing. The shoulder prevents the bullet from passing through the cement sheath and forming large openings in the sheath which could pass sand into the casing. Furthermore, since the bullet does not pass through the cement sheath and into the producing formation, there is no forcing of mud under high pressure into the formation. Therefore, when the method of the invention is applied to the completion of a well in a consolidated or competent formation, the low permeability which results from the forming of a mud cake or plug in the bullet channels in wells completed by conventional bullet perforation, is avoided in the method of my invention.

Further description of the details of the invention can best be given by referring to the drawing of which Figure 1 is a diagrammatic sectional view of a producing formation in an oil well showing a phase in the completion of the well by the method of the invention; Figure 2 is a diagrammatic sectional view of the producing zone of an oil well completed in accordance with the method of the invention; and Figure 3 is a diagrammatic perspective view of a bullet used in the method of the invention.

Figure 1 shows, by way of example, a well extending through a consolidated formation **10**, an unconsolidated oil sand **11** and into a consolidated formation **12**. The well is cased throughout the producing formation with a tubular casing **14**, which is preferably steel casing pipe commonly used in the art. The casing **14** is surrounded by a cementitious sheath **15**, formed preferably from a slurry of neat Portland cement. Care is taken to eliminate voids or channels from the cement sheath **15** before it sets, for example by using scratchers and centralizers in the cementing operation. After the cement has set, the well is ready for the phase of the method of the invention in which fractures are formed in the cement sheath and perforations are formed in the tubular casing.

In my invention, a modified gun perforating device **20** is lowered into the well to the level of the producing formation as shown in Figure 1. Gun perforating devices, well known in the art, are provided with one or more gun barrels for firing projectiles into the inner wall of a well casing. A known type of firing device may be employed, but in my invention the gun is modified in that the barrels are loaded with bullets generally of the structure indicated in Figure 3 and each having a smaller than conventional powder charge of amount to be explained later. A basket **24** whose purpose will also become evident later may be suspended below the gun as shown.

Figure 3 shows a bullet which is used in my invention. It is conveniently of caliber to fit a commercially-available perforating gun barrel, and has a cylindrical body portion **25** and coaxial with the body portion, a generally-pointed nose portion **27**. The nose portion may be conical or pyramidal or other generally-pointed shape with sharp or slightly rounded point, and may have a fillet at its base. The base of the nose portion **27** is substantially smaller in cross-section than the cylindrical body **25**, thus forming a shoulder **28** at the juncture of the base of the nose portion and the body of the bullet. This shoulder **28** is adapted to impede the penetration of the bullet into the well casing pipe to a depth greater than the length of the nose **27**, and thereby arrest the bullet before the body portion **25** traverses the well casing. The nose **27** of the bullet should have a length somewhat greater than the known thickness of the casing **14**.

In my invention, bullets of the structure illustrated in Figure 3 are fired by the modified gun device **20** against the inner wall of the well casing. When the proper propellant charge is used, the bullet pierces the casing, but its forward motion is arrested by impact of the shoulder **28** against the casing **14**, so that the bullet does not pass through the casing or the cement sheath. In most instances, the shoulder causes the bullet to rebound from the hole in the casing wall, leaving a small tapered perforation produced by the point **27**. If bullets should remain in the casing wall, the perforations can be cleared by means of a scraper.

When the shoulder bullets used in my invention are fired with a properly selected propellant charge against the casing wall, they impart a sharp physical shock to the cement sheath. Thus, without penetrating to any substantial extent into the cement sheath, the bullets apply a stress which fractures the sheath and forms a system of hair-line fractures or cracks therein.

The well structure resulting from carrying out my invention for completing a well is illustrated in Figure 2 of the drawing. As the figure shows, the tubular casing **14** is positioned within the producing formation coaxial with the bore hole and is surrounded by a cement sheath **15**. The casing **14** in the producing formation contains perforations **18** in its walls which were pierced by the point **27** of the bullets employed in the invention. The cement sheath **15** in the producing formation contains a system of small fractures or fissures **22** caused by the shock of the bullet shoulder **28** striking against the tubular casing **14**. The fractures are the only openings in the cement sheath; there are no large passages such as would be formed by a bullet passing completely through the sheath. The small fractures, which are the only openings in the sheath, pass fluids from the unconsolidated producing formation into the perforations in the well casing but prevent the passage of sand in any substantial amount. The sheath retains its original general outline as Figure 2 shows, and continues to provide support for the surrounding unconsolidated sand formation so that the shifting of sand which causes clogging in wells completed in sand formations by conventional methods is avoided.

The caliber and the material of composition of bullets employed in the practice of the invention can vary depending upon the wall thickness of the particular casing to be pierced and the thickness of the sheath to be fractured. Bullets of calibers and of materials conventionally used for perforating well casing are suitable, such as steel alloy bullets of from about 1/16 to 9/16 inch in diameter. The proper propellant charge for the bullets is substantially smaller than that normally employed for casing perforation by conventional methods wherein bullets are fired into the producing formation after completely traversing the casing and its cement sheath. The reduced propellant charge and the effect of the bullet shoulder **28** prevent the bullets from passing through

the casing into the cement sheath. In the practice of my invention, the propellant charge should be from about 1/4 to 3/4 the charge normally employed to propel bullets of the same caliber in conventional casing-perforation operations in which the bullet entirely traverses the casing and its cement sheath, the proper charge in any particular instance being readily determinable by any one of several procedures to be described.

The efficacy of my invention for piercing casing and cracking a cement sheath surrounding the casing was determined in the following test set-up. Inasmuch as it is impossible to recover the cement sheath, the test operation was conducted in a shallow test hole. In one such test a section of 5½ inch casing was cemented concentrically inside a 9⅝ inch casing. After the cement had set, a 4 foot by 8 inch section was cut from the side of the outer casing to serve as a window for observing the result of the invention. The outer pipe was then wrapped with wire about the cut-away portion and the assembly was lowered into a shallow test hole. A gun perforating device was lowered into the inner casing and 10 shoulder bullets of the structure shown in Figure 3 of the drawing, 0.471 inch in diameter and loaded with one-half the normal propellant charge, were fired into the inner wall of the 5½ inch casing. The assembly was raised from the hole and examined. It was found that the bullets had pierced the inner 5½ inch casing and had fractured the cement sheath. The fractures in the cement were fine but numerous and radiated outwardly from the holes punched in the inner casing. Each of the bullets stopped when its shoulder struck the inside of the 5½ inch casing and most of the bullets bounced back leaving a clear hole in the casing.

It is important in the practice of my invention that the powder charge be properly related to the weight and diameter of bullet, length of barrel (which is determined by the available hole diameter) and the type of casing which it is desired to pierce. The above-described test procedure may also be used to experimentally determine the proper amount of propellant charge to be employed so that the bullet nose **27** will pierce the casing but the bullet will be arrested when its shoulder **28** strikes the casing. By way of example, a bullet having the shape illustrated in Figure 3, weighing 14.45 gram, having an outside diameter of 0.471 inch, and a nose **27** in the shape of a cone of base diameter 5/16 inch and height ½ inch, was fired with reduced charge from a commercially-available 4 inch gun into a short length of 7 inch type J–55 casing (wall thickness 0.3 inch) in the above-described test set-up. The charge customarily used in this gun for conventional casing-perforating service is 10 grams, which charge is sufficient to cause the bullet to entirely traverse the casing and its cement sheath. The above-described bullet of my invention, fired from this 4 inch gun with only a 5 gram powder charge produced a tapered hole in the 7 inch type J–55 well casing, the hole tapering down to approximately 3/16 inch in diameter at its outer end, and the shoulder of the bullet indented the steel less than 1/16 inch. The proper propellant charge to cause the bullet to pierce the casing but not traverse the casing is thus readily determinable in the test set-up described above wherein the known casing string (or strings) and the cement in the well around the casing may be duplicated.

Alternatively the proper charge may in any particular instance be determined directly in the well by reducing the conventional charge known to be required for the bullet to entirely traverse the casing until it is found that the bullets may be recovered inside the well, for example, by means of a basket carried beneath the shooting gun as indicated generally by **24** in Figure 1 or by means of a fishing magnet (not shown). The basket **24** should be of the drillable type and may be connected to the gun **20** by means of a shear pin **25** so that the gun may be re-

covered in the event that the basket gets stuck. The basket 24 may have the conventional form of an inverted umbrella made of reinforced rubber or other drillable material and constructed so that its periphery conforms approximately to the inner surface of the casing. The proper quantity of propellant charge for use in my invention is one which is reasonably large but which allows the bullet to remain in the well bore, rather than cause the bullet to traverse the casing and lodge in the surrounding cement sheath. In a well in any particular situation, the proper weight of charge is readily determined as the maximum charge which still allows the bullet to be recovered from the well bore. The bullets may be recovered in the basket 24 or by means of a junk basket or fishing magnet subsequently run into the hole. The efficacy of the piercement may be determined by applying liquid (preferably oil) under pressure to the well over the depth interval concerned, and if the liquid readily passes through the casing it is known that the casing has been pierced. By way of example, in one well a number of 14.45 gram bullets 0.471 inch in diameter were fired from a 4 inch gun with 3 gram propellant charges, the bullets being afterward recovered. The depth interval was then pressure tested with oil but found not to be open. The gun was then reloaded with similar bullets but each with a 4 gram propellant charge. Subsequent to firing the bullets were again recovered, but a pressure test showed that there was still no communication to the formation. The gun was then again reloaded with similar bullets and each was given a 5 gram propellant charge. Subsequent to firing the bullets were again recovered and a pressure test with oil showed that communication to the formation had this time been established. Accordingly, the 5 gram charge was indicated to be the proper charge for use in this well or others having similar well equipment.

The steps to be followed in the practice of my invention are to cement the casing through the producing formation taking care to obtain the best possible cement job and avoiding the formation of all voids in well known manner. At the same time a short length of the same casing may be cemented into a short length of larger casing to form a test set-up as previously described to duplicate well conditions at the surface. A commercially-available casing-perforating gun of the conventional type is then charged with the shoulder bullets of my invention, and with several different powder charges each smaller than that conventionally used with bullets of comparable weight. After the cement in the test set-up has properly set, the bullets are fired in the test set-up and it may be found that the largest charge causes the bullet to entirely traverse the casing, whereas the smallest charge will be insufficient to cause the bullet to even pierce the casing at all. An intermediate charge will be found which causes the bullet nose to pierce the casing but the bullet will still remain inside the casing. The largest charge which will do this is indicated and the gun may then be loaded with this charge for shooting in the well. This gun 20 and basket 24 may then be lowered into the well and the gun fired opposite the producing formation. Upon removing the gun and basket from the hole, the bullets will be found recovered in the basket 24. Alternatively to using the basket 24 on the gun, the bullets may be recovered with a magnet or a junk basket subsequently run to the bottom of the hole. As a further check on whether the casing is pierced and the cement fractured, oil may be spotted opposite the formation and pressure applied by means of a pump at the surface. If communication to the formation exists, the oil will move out into the formation. Subsequently, of course, the well is put on production in conventional manner.

After the well is completed in accordance with my invention, if it should appear that insufficient fractures had been developed in the cement sheath and that the cement is not permeable enough for the desired rate of production of fluids, the fractures can be made more permeable by any of a number of well known methods, for example, by treatment with an acid such as hydrochloric acid. In the event that the casing had been pierced, without fracturing the cement sheath at all, such fractures may be produced by one of the techniques described in the afore-mentioned Teplitz applications.

In the foregoing description, I have referred only to the completion of a well at a single producing level. However, it should be understood that a well drilled through a plurality of producing formations can be completed at each level by the method of my invention so that production can take place simultaneously from each formation. This characteristic of my method is an important advantage over conventional methods of well completion, such as gravel packing, which cannot be applied to widely separated producing zones in a single well.

Obviously many modifications and variations of the invention as hereinbefore set forth may be made without departing from the spirit and scope thereof and therefore only such limitations should be imposed as are indicated in the appended claims.

I claim:

1. Apparatus for piercing pipe in a well comprising a gun barrel adapted to be lowered into the well, means for firing said gun, a bullet in said gun having a cylindrical body portion and a generally conical nose portion coaxial with the body portion, the length of said nose portion being greater than the thickness of the pipe to be pierced, the base of the conical nose being substantially smaller in diameter than the cylindrical body and thereby forming at the juncture of said nose and body an annular shoulder adapted to impede penetration of the body portion of the bullet into the pipe, an explosive charge in said gun adapted to propel said bullet from the gun with a velocity sufficient to effect piercement of the pipe by said conical nose but insufficient to cause perforation of the pipe by the body portion of the bullet whereby said bullet remains inside the pipe, and means attached below said gun adapted to catch said bullet.

2. Apparatus adapted to punch a hole in a target which comprises a gun barrel, a bullet having a substantially cylindrical body portion and a generally pointed nose portion coaxial with said body portion, the length of said nose portion being greater than the thickness of the target, the base of said pointed nose being substantially smaller in cross-section than said body portion and thereby forming at the juncture of said nose and body a shoulder adapted to impede penetration of the body portion of the bullet into the target, and a propellant for said bullet adapted to propel said bullet from the gun barrel with a velocity sufficient to effect piercement of the target by the nose of said bullet but insufficient to cause perforation of the target by the body portion of the bullet.

3. A method of completing a well in which a casing is cemented in the producing formation, comprising the steps of piercing the casing with a solid object to make an opening therethrough, and simultaneously striking the inner surface of the casing about the periphery of the opening pierced in the casing with said solid object to apply a sharp physical shock to the casing sufficient to fracture the cement surrounding the pierced portion of the casing to form small cracks in the cement communicating between the producing formation and the opening pierced in the casing.

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