ABSTRACT: A well completion apparatus for perforating and injecting a fluid into a formation surrounding a cased wellbore. The apparatus includes a body unit defining an enclosed chamber, a perforator mounted in the chamber, a conduit in fluid communication with the chamber and adapted to conduct fluid from the surface to the chamber, and a mechanism for firing the perforator to form a flow passage between the formation and the chamber.
WELL PERFORATING AND TREATING APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an apparatus for placing a treating fluid in a formation surrounding a wellbore.

2. Description of the Prior Art

In completing wells in unconsolidated formations, consideration must be given to the sand problems likely to arise during operation of the wells. The migration of formation fines can be controlled by a variety of sand control techniques, all of which in effect establish a sand exclusion zone through which the formation fluids must pass en route to the wellbore. The sand exclusion zone can be provided by mechanical means, e.g., liners, screens, gravel packs, or by consolidation with plastics.

The present invention is concerned with fluid-treating subterranean formations and has particular application in the placement of sand consolidating plastics. The concept of forming a coherent permeable sheath about the wellbore by use of thermostetting plastics has long been known. However, widespread application of the plastic consolidating principle awaited development of techniques and tools for performing the consolidation process. One such tool recently developed is the so-called “shoot-and-inject” tool. This tool obviated many of the problems previously experienced in performing sand consolidation treatment, particularly in the placement of the plastic. The tool is designed to selectively and incrementally place plastic in the formation. Its components include a perforator for forming a single isolated perforation in the casing and an assembly for injecting the treating fluids through the perforation—hence, the name “shoot-and-inject” tool. The assembly for injecting the chemicals includes a reservoir provided with a valve system for maintaining the chemical components segregated during running and injection operations. All of the components are self-contained, permitting running and operation on conventional wire line equipment.

The self-containment construction of the “shoot-and-inject” tool limits the treatment volume to the relatively small capacity of the reservoir. Field experience has indicated that the success of a plastic consolidation treatment depends to a large extent upon the volume of plastic injected. Generally the recommended chemical volume is in the range from 20 to 50 gallons for each foot of formation to be treated. This size of treatment requires that the chemicals be placed in the formation by the “through-tubing” technique. This technique places the chemical in the formation by surface pumping through the tubing and permits surface control of injection volumes, rates, and pressures. However, it sacrifices the selectivity feature offered by the “shoot-and-inject” tool.

In addition to the capacity limitation described above, the “shoot-and-inject” tool presents certain operational problems. It is essential to the operation of the tool that the target area be isolated prior to the actuation of the perforator. Target isolation generally is provided by an annular sealing member which, when pressed against the interior surface of the casing by the action of a hydraulic ram, establishes a pressure seal between the passage formed by the perforator and the wellbore. The sealing member, hydraulic ram, and ram actuator increase the complexity of the tool construction and tool operation.

SUMMARY OF THE INVENTION

The well completion apparatus constructed according to the present invention combines the selectivity of the “shoot-and-inject” tool and the injection capabilities of the “through-tubing” placement technique. The apparatus includes a body unit which defines an enclosed chamber, perforating means mounted in the chamber, and a conduit in fluid communication with the chamber. With the body located opposite the zone to be consolidated, the conduit extends to the surface, providing a fluid conductor to the unit chamber. When the perforator is actuated, a passage is formed between the unit chamber and the formation permitting the injection of a treating fluid into the chamber via the conduit, the unit chamber, and the passage. A plurality of the body units can be arranged in stacked relation and selectively actuated so that the formation is treated in vertically adjacent intervals. Moreover, since the injection volume is controlled by surface facilities, the dimensions of the tool are restricted only to that which will house the internal components, e.g., perforating means. Using conventional-shaped charges as the perforating means, the outside diameter of each unit can be sized to pass readily through 2 ½ inch casing. Thus the “shoot-and-inject” technique can be used in tubingless completions.

Since the apparatus does not require the isolation of the target area, the annular seal and hydraulic ram required on the presently known “shoot-and-inject” tools can be eliminated, thereby greatly simplifying the structure and operation of the tool.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a sectional view of a wellbore showing the completion apparatus constructed according to the present invention disposed opposite an unconsolidated formation.

FIGS. 2 and 3 are views similar to FIG. 1 showing the apparatus and hole conditions at various stages in the treating process.

FIG. 4 is an enlarged longitudinal sectional view of the unit shown in FIGS. 1 through 3.

FIG. 5 is a transverse sectional view of FIG. 4 taken generally along the cutting plane indicated by the line 5—5 thereof.

FIG. 6 is a wiring diagram for the perforating means used in the assembly of units shown in FIGS. 1 through 3.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

With reference to FIG. 1, the well completion apparatus, referred to generally as 10, is shown suspended in a cased wellbore 11 opposite an unconsolidated formation 12. The wellbore 11 has been drilled from the earth’s surface and is provided with a casing string 13 surrounded by a cement sheath 14. Preparatory to completing the well, the casing is filled with a light completion fluid, e.g., diesel oil, with a lower section (rat hole 16) remaining occupied with salt water.

The apparatus 10 includes generally an assembly comprising a conduit 17 and a plurality of body units, e.g., a first unit 18, a second unit 19, and a third unit 20. The units 18, 19, and 20 are arranged in axially aligned and stacked relation so that when the assembly is located opposite the formation 12, the units confront vertically spaced intervals thereof.

Since each unit is identical in structure to permit interchangeable use, only the lower unit 18 will be described, with like-primed and double-primed reference numerals being assigned to corresponding parts of the middle and upper units, 19 and 20 respectively.

As shown in FIGS. 4 and 5 each unit, e.g., 18, includes a cylindrical hollow body 22 having top and bottom closure members 23 and 24. The assembled body 22 defines an enclosed chamber 25. An annulated tube 26 extends through the chamber 25 terminating in threaded ends on either side of closure members 23 and 24. The annulated configuration of tube 26 provides clearance within chamber 25 for the perforating means. The tube has port means in the form of a perforated section 27 communicating with the chamber 25. As described below, the perforated section 27 provides fluid communication between the conduit 27 and the chamber 25. The annular portions of the tube 26 are smoothly rounded to permit the passage of sealing members through the interior of the tube 26.

A perforator gun 28 mounted in chamber 25 is detonated by an electric firing mechanism 29 comprising a battery 30, a detonator 31, and a pressure switch 32. The perforator gun 28 can be of any conventional construction but preferably the perforators shown as 33 and 34 are jet perforators contained
in an enclosed carrier 36 so that the firing thereof will not damage other unit components. With the carrier 36 secured to the inner wall of body 22, the perforators 33 and 34 are oriented to fire in a direction which lies in a plane passing through the axes of body 22 and carrier 36 away from tube 26.

The units 18-20 are identical in structure and operation. Therefore any number of units can be assembled in any order by merely coupling together the exposed threaded ends of the respective tubes 26 (see FIG. 1). The upper exposed end of tube 26' can be coupled to the conduit 17 for running-in operations, the lower exposed end of member 26 being provided with a perforated cap 37. Thus when the assembly is located opposite the formation 12, the conduit 17 in fluid communication with each of the members 25, 25', 25" through tubes 26, 26' and 26" provides fluid coolant means for delivering treating fluid to each of the units 18-20 and to the wellbore 11. The total number of units in the assembly will depend upon the thickness of the zone to be treated. The spacing of the perforators 33, 34, 33', 34', etc. of the entire assembly preferably should provide a perforation density of about one hole per foot. If the thickness of the zone to be consolidated approximates 6 feet, the assembly will normally comprise three units as shown in FIGS. 1-3.

The pressure switch 32 wired into the electric firing circuit as shown in FIG. 6, serves the dual function of detonating the associated perforating gun 28 and arming the firing mechanism of the vertically adjacent unit. Each pressure switch 32 closes in response to a predetermined fluid pressure in its associated chamber 25. The pressure switch 32 of the bottom unit 18 is preset to close at a pressure substantially above the wellbore static pressure.

With the assembly of units 18-20 located at the proper depth, the fluid pressure in the chambers 25, 25', 25" is gradually increased by means described below. When the pressure in the bottom chamber 25 reaches the preset pressure of switch 32, the electric circuit for the perforating means enclosed therein is completed, causing the perforator gun 28 thereof to fire. In addition to firing the perforators, the closing of the switch 32 establishes a ground connection for the firing circuit of the vertically adjacent unit 19 thereby placing it in condition for firing. Firing of the middle unit perforator gun 28' is occasioned by the continued increase in system pressure the preset pressure of the middle unit switch 32' being sufficiently greater than that of the bottom unit switch 32 to ensure independent and selective response. The closing of the middle unit switch 32' fires the middle unit perforator gun 28' and arms the top unit firing mechanism 29' in the manner described above. The preset pressure of switch 32' is sufficiently greater than that of the preset pressure of 32 to ensure independent and selective response to increase in pressure in chamber 25'. The pressure switches can be conventional single-pole, single-throw switches provided with a 5-10 second time delay to prevent premature actuation by explosive shock waves. A pressure gap of 30-50 p.s.i. in the settings of switches 32 and 32' is normally sufficient to enable independent and selective actuation of the firing mechanisms 28, 28', and 28". The switches 32, 32', and 32" can be differential pressure switches set to close at a predetermined pressure above the wellbore pressure.

As indicated above, the tubes 26, 26', and 26" are connected in series, and with the conduit 17 provide conductor means from the surface to and through each unit 18-20. During run-in operations, circulation can be maintained between the conduit 17 and the wellbore 11 through the passage provided by the perforated cap 37. When the assembly of units 18-20 is properly located opposite the zone to be treated, sealing members 38 are pumped through the conduit 17 and the tubes 26", 26', and 26. The member 38 is received in sealing relation on a suitable seat provided in the lower end of tube 26. This interrupts fluid communication with the wellbore so that pressure buildup in the chambers 25, and 25" can be effected by the operation of surface pumps. The pressure is gradually increased in the system until the lowest preset pressure (switch 32) is reached. The ensuing detonation of perforators 33 and 34 forms two fluid passages 39, 39 between the chamber 25 and the formation 12. This permits the injection of treating fluids into the formation 12 via conduit 17, tubes 26", 26', 26 chamber 25 and flow passages 39 by the surface pumps.

While a variety of wipers or plugs can satisfactorily serve as the sealing member 38, it is preferred that the sealing member be spherical in configuration and composed of a resilient material such as hard rubber or neoprene. The resilient balls provide adequate separation between different chemicals used in the treatment and yet are deformable under differential pressure to sealingly engage the internal wall of the tubes 26, 26', and 26''.

In order to increase the pressure in the vertically adjacent unit 19, a sufficient number of balls 38 are introduced into the fluid conducted to chamber 25 to seal the perforated section 27 of tube 26 (see FIG. 2). The closing of the lower chamber 25 permits pressuring-up of the middle chamber 25 by operation of surface facilities. The pressure is gradually increased to the preset pressure of switch 32'. The resulting actuating of the middle unit perforating means forms flow passages 39' between the formation 12 and middle unit chamber 25'. This interval which is vertically spaced from the lower treated interval then can be treated by operation of surface facilities. Again a sufficient number of sealing members are introduced into the treatment stream to effect closure of the perforated section 27'. Thus each unit can be actuated in a steplike order permitting the sequential treatment of the formation 12 in vertically adjacent intervals. Moreover, the separate firing mechanism for each unit permits the firing of their associated perforators at selected time intervals.

Under certain conditions, as where the treating fluid density is lighter than or equal to the completion fluid density, it may be necessary to provide packing members on either side of the zone to be treated. In this event, flexible, annularly shaped rubber wipers 40 can be mounted on the top of unit 20 and the bottom of unit 18. During run-in, pulling-out, and circulation operations, the flexible wipers 40 fold back, permitting the passage of fluid thereby.

The operations of the apparatus constructed according to the present invention will be briefly described with reference to FIGS. 1, 2, and 3. The number of units 18-20 assembled and wired together in the manner described above is determined by the length of the interval to be consolidated in this embodiment three units 18-20 are so assembled. The assembly is attached to the conduit 17, run in the wellbore 11, and located opposite the zone to be treated. The initial treatment volume is pumped into the conduit 17 while taking returns on the casing 13. The leading portion of the treating fluid is provided with a plurality of sealing balls 38 such that when the fluid reaches the perforated section 27 of unit 18, the final ball is located slightly below the perforated section. This condition will be reflected at the surface by a slight increase in pump pressure since the leading ball is sealingly received in the lower end of tube 26. Fluid is slowly pumped into the conduit 17 causing an increase in pressure in the lower chamber 25. The pressure-responsive perforating means is actuated forming a fluid passage 39 between the formation 12 and chamber 25. This permits the injection of treating fluid into the formation 12 forming a generally spherical shaped invaded zone. The trailing portion of the treating fluid is provided with a sufficient number of balls 38 to pressure seal the bottom unit perforated section 27. Again the pressure is gradually increased, actuating the pressure-responsive perforating means of the middle unit 19. The middle unit is treated as previously described, the trailing portion of the treating fluid being provided with a plurality of balls 38 which upon completion of the treatment seals the middle unit perforated section. Again the pressure in the column is gradually increased, actuating the perforating means of the top unit 20 forming passages 39'. This permits treatment of the top inter-
val. At the conclusion of the treatment, the invaded zone of the formation will be of general cylindrical shape as depicted in FIG. 3.

In order to ensure the sequential treatment of the vertically spaced intervals, a plugging solution such as an oil base mud can be used following each treatment so that the fluid passages 39, 39', and 39'' are temporarily plugged. These plugs can be removed by producing the well.

The well completion apparatus of this invention has particular application in plastic, sand consolidation treatments. Each vertically adjacent interval can be treated with a plurality of chemicals comprising a preflush, a plastic resin, a hardener or catalyst, and a plugging solution. In treating each interval the various solutions can be separated by one or more of the sealing balls 38 which can be collected in stacked relationship in the tubes 26, 26', and 26''. The apparatus can be used in the placement of any the presently known sand-consolidating plastics, the most important of which are the epoxy resins, the phenol-formaldehyde resins, and the furan resins. It can be used in premixed system (resin and catalyst mixed before placement) or in situ mixed system (resin and catalyst mixed in the formation).

1 claim:

1. An apparatus for treating a subterranean formation surrounding a wellbore, said apparatus comprising a conduit, a body unit supported on said conduit and defining an enclosed chamber, said conduit having fluid conductor means in fluid communication with said chamber and in fluid communication with said wellbore; a perforator mounted in said chamber; means for actuating said perforator in response to a predetermined pressure in said chamber; and means for closing the conductor means in fluid communication with said wellbore.

2. The invention as recited in claim 1 wherein said fluid conductor means includes a tube extending through said chamber, said tube having a lower end communicating with said wellbore and port means communicating with said chamber.

3. The invention as recited in claim 2 wherein said means for closing said conductor means communicating with said wellbore includes a seat formed in said lower end of said tube and a sealing member passable through said conduit and said tube and engageable with said seat in sealing relationship.

4. A well completion apparatus for fluid treating a subterranean formation surrounding a cased wellbore, said apparatus comprising: a lower body unit defining an enclosed chamber; an upper body unit defining an enclosed chamber, said units being assembled in vertically spaced relationship; a conduit in fluid communication with each of said chambers and adapted to conduct a treating fluid to each of said chambers; and means for actuating said perforating means in said upper and lower units at selected times.

5. The invention as recited in claim 4 wherein each of said perforating means includes a perforator gun and firing mechanism operatively responsive to a predetermined fluid pressure in said conduit, the predetermined fluid pressure for actuating the lower unit firing mechanism being substantially lower than the predetermined fluid pressure for actuating the upper unit firing mechanism, and said means for actuating said perforating means includes means for increasing the pressure in said conduit to actuate said lower unit firing mechanism and then to increase the pressure in said conduit to actuate said upper unit firing mechanism.

6. The invention as recited in claim 5 wherein said lower unit perforating means includes means for arming said upper unit firing mechanism responsive to actuation of said first unit firing mechanism.

7. The invention as recited in claim 6 wherein said means for increasing the pressure in said conduit includes a sealing member passable through said conduit and lodgeable in said lower unit to interrupt fluid communication between said lower unit chamber and said conduit.

8. The invention as recited in claim 8 wherein said conduit includes a tube extending through said upper unit chamber and being connected in fluid communication with said lower unit chamber, said tube having port means communicating with said upper unit chamber, said sealing member being adapted to lodge in said tube to interrupt fluid communication between said upper unit chamber and said lower unit chamber.

9. The invention as recited in claim 8 wherein each unit perforator gun includes a plurality of vertically spaced jet perforators, the unit spacing and jet perforator spacing being such to provide a shot density of about one shot per foot of thickness of the formation to be treated.

10. A well completion apparatus for fluid treating a subterranean formation surrounding a cased wellbore, said apparatus comprising: a lower body unit defining an enclosed lower chamber; at least one upper body unit defining an enclosed upper chamber; means for assembling said lower body unit and said upper body unit in axial and spaced-apart alignment; a conduit adapted to support and locate the assembled units opposite said formation and providing conductor means for delivering treating fluid to each of said chambers; perforating means mounted in each of said chambers; means for first actuating said perforating means of said lower unit to form a fluid passage between said lower chamber and said formation, and then actuating said perforating means of said upper unit to form a fluid passage between said upper chamber and said formation.