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[54] **METHOD AND APPARATUS FOR
CONSOLIDATING A SUBSURFACE EARTH
FORMATION**

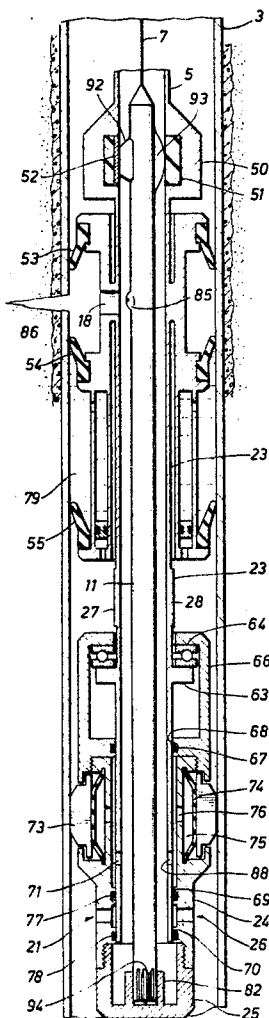
29 Claims, 4 Drawing Figs.

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166/286, 175/4.52
[51] Int. Cl. **E21b 33/138**
[50] Field of Search 166/250,
255, 286, 290, 291, 297, 55.1, 100; 175/4.51, 4,
4.52

[56] **References Cited**
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ABSTRACT: Methods and apparatus are provided for treating an unconsolidated subsurface earth formation. Means are provided for isolating and perforating a preselected section of a wellbore, and thereafter sequentially introducing selected formation treating agents into the perforated formation. After these materials are in the formation, a suitable temporary plugging agent is deposited in the perforation, to prevent its collapse, as well as to block the entrance of wellbore fluids. In the apparatus, the plugging agent is held in the annulus defined by a pair of spaced-apart elastomeric packing cups, and the equipment is merely shifted to position the cups above and below the perforation to enable the plugging agent to flow into the perforated formation. The apparatus preferably includes provision for a closeable bypass around the plugging agent held between the cups, whereby the apparatus may be moved up or down a fluid-filled casing without disturbing the plugging agent.



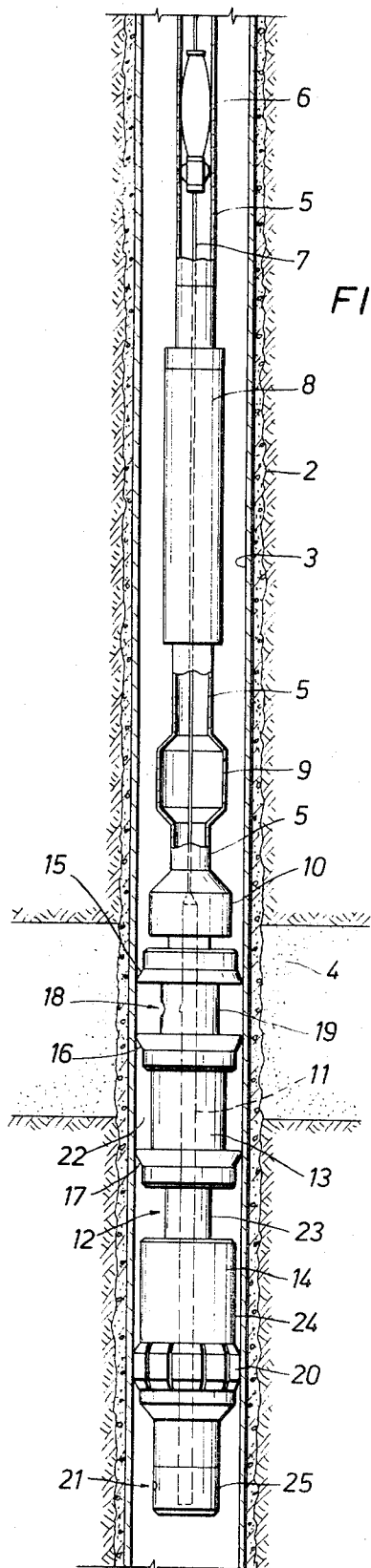


FIG. 1

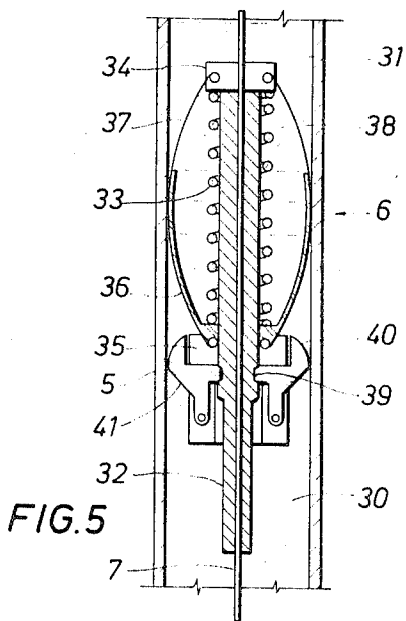


FIG. 5

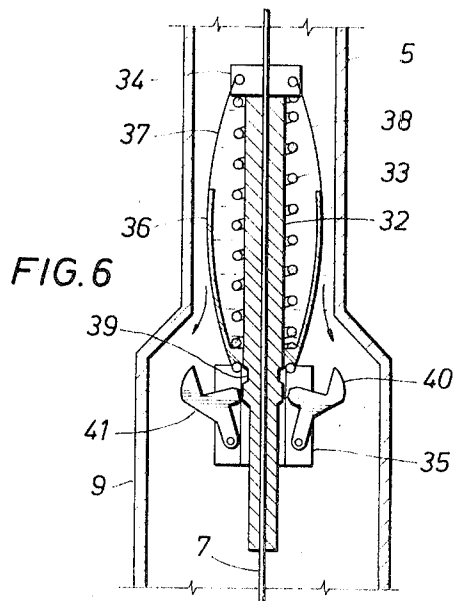
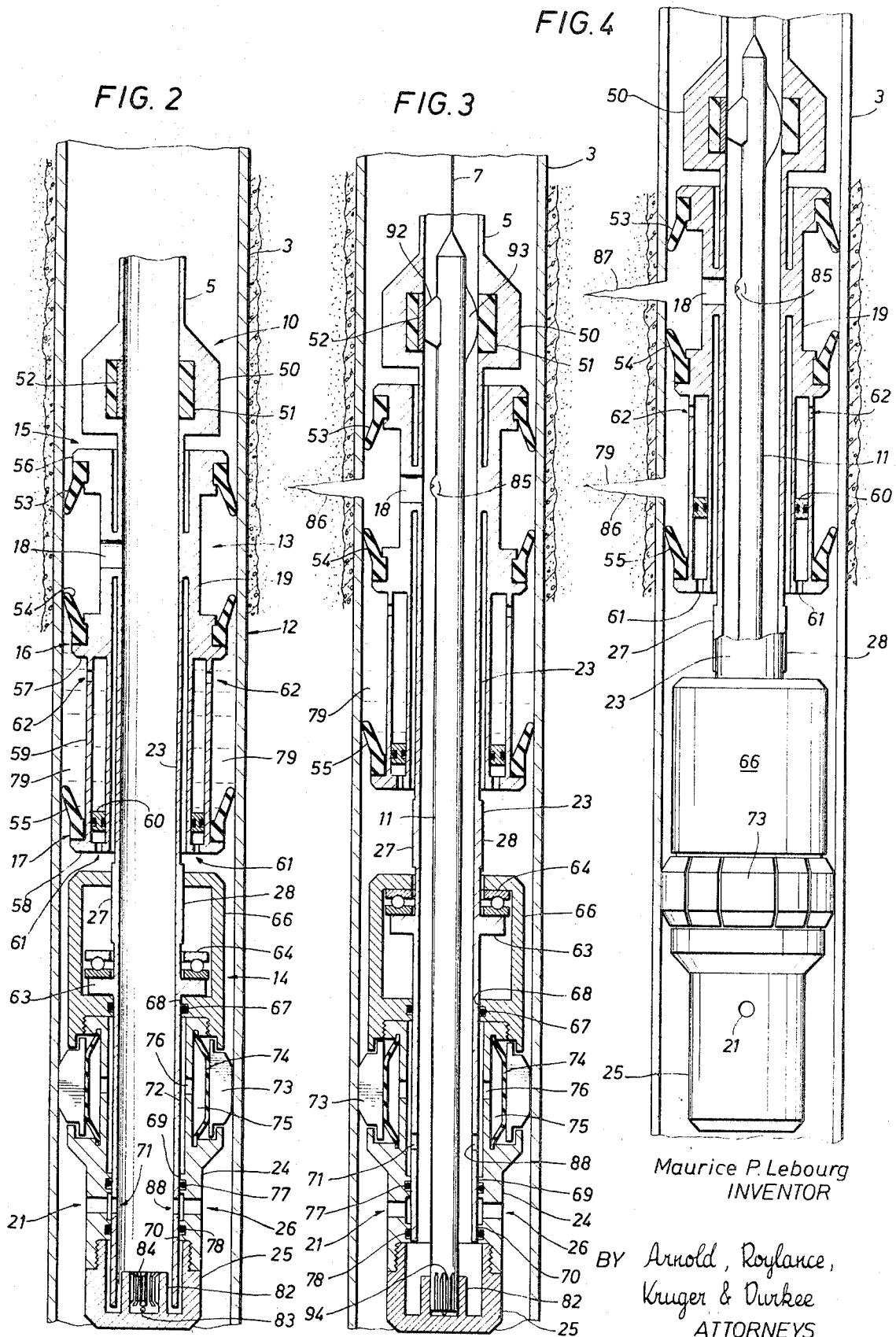


FIG. 6

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FIG. 7

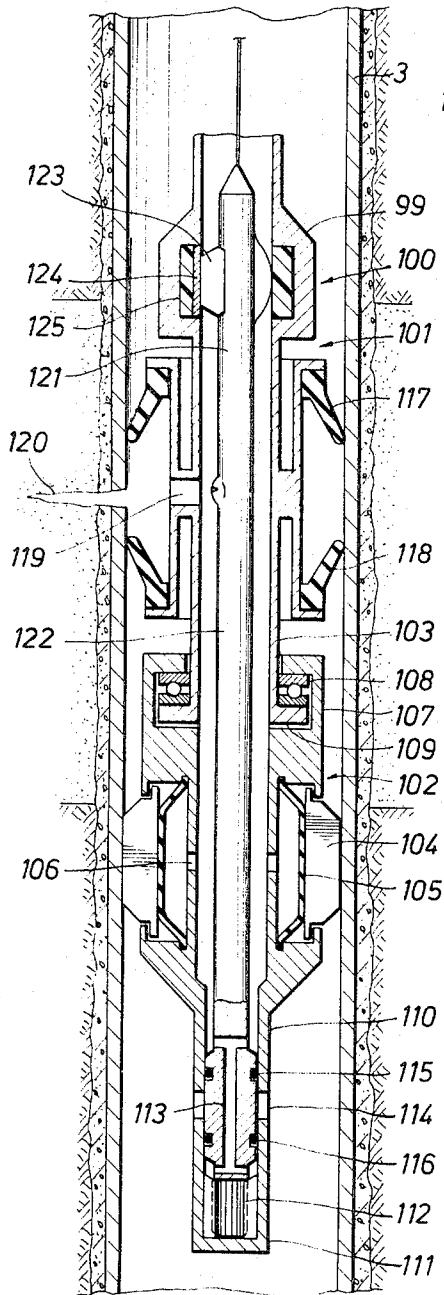
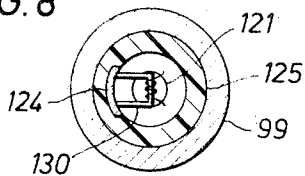


FIG. 8



TO CABLE

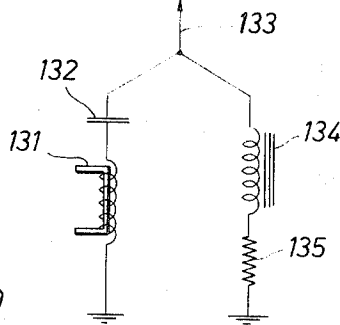


FIG. 9

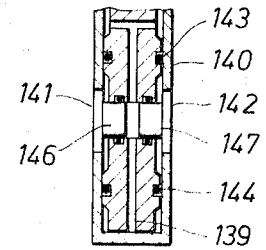


FIG. 10

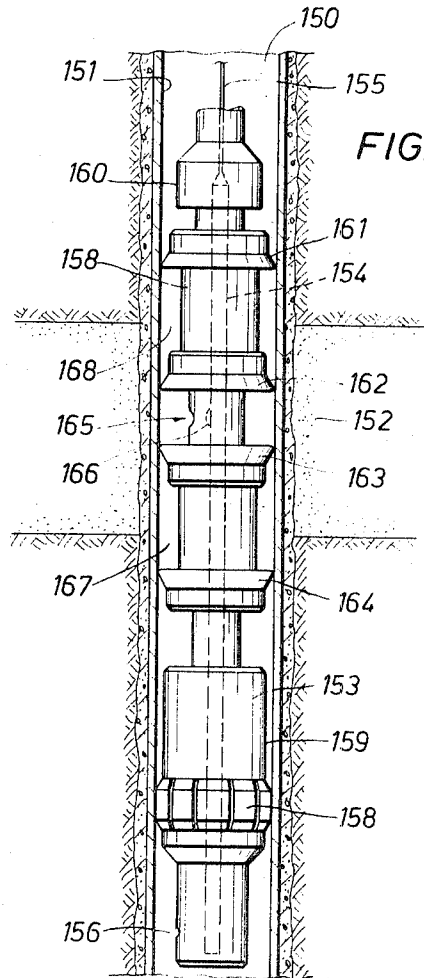


FIG. 11

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METHOD AND APPARATUS FOR CONSOLIDATING A SUBSURFACE EARTH FORMATION

BACKGROUND OF INVENTION

This invention relates to methods and apparatus for inhibiting sand flow from unconsolidated earth formations traversed by a borehole, and more particularly relates to methods and apparatus for consolidating these formations adjacent the borehole.

It is well known that oil and gas is found in subsurface earth formations, and that boreholes are drilled from the surface of the earth for the purpose of tapping these formations. It is also well known that the fluids enter the borehole through perforations in a steel casing or tubing, which is suspended in the borehole and which functions therein as a conduit between the formation and production equipment at the surface.

Many fluid-bearing formations are relatively unconsolidated, and in these instances, individual grains of rock or sand tend to become dislodged from the matrix of the formations and are carried into the casing by the fluid sought to be recovered. Some of the loose sand grains will be carried to the surface, and this will tend to severely damage sensitive portions of the production equipment. Much of the sand will merely accumulate in the casing, however, and thus the accumulated sand may eventually interrupt fluid flow into the perforated casing. Inasmuch as there is a trend in the oil and gas industry to provide only one, or at the most only a very few perforations at carefully selected locations in the casing, there is increased likelihood that production from an unconsolidated formation will be interrupted in this manner by sand accumulated in the casing.

Many techniques have been devised for the purpose of alleviating the problem. For example, the borehole may be enlarged and packed with gravel adjacent the formation to provide a filter system. Alternatively, strainers or screens may be installed in the casing or tubing string also for the purpose of filtering loose sand out of the incoming fluid. These techniques are often only temporarily successful, however, and thus it is often necessary to perform expensive workover operations at frequent intervals in order to maintain the productivity of the well.

Accordingly, methods and apparatus such as those described in U.S. Pat. No. 3,153,449 granted to Maurice P. Lebourg, and U.S. Pat. No. 3,174,547 granted to Roger Q. Fields, have been developed for the purpose of attaching the essence of the problem by improving the consolidation of the formation adjacent the borehole. In this technique, a suitable bonding or consolidating agent is injected through the perforation in the casing, and into the formation where, in time, it will react and harden. The agent or "plastic" is intended to generally surround or coat the individual sand particles and thereby cement them together. Depending on the particular agent selected, the pore spaces between adjacent grains are left open in one way or another, so that the formation matrix will remain permeable to the formation fluids.

As more particularly described in U.S. Pat. No. 3,361,204 issued to G. C. Howard et al., a special assembly adapted to support a perforating gun is disposed adjacent the selected formation. The section of the borehole adjacent the formation is then isolated by expandable seals, and the casing may then be perforated with one or perhaps two charges in a selected direction. A liquid preflush such as kerosene may then be injected into the isolated section of the borehole, and through the perforation, to wash out loose sand, casing particles and other debris. Thereafter, a suitable cementing material such as an epoxy plastic may be injected into the isolated borehole section and into the perforated formation, and maintained therein until the plastic solidifies.

It is necessary that the plastic material remain in a liquid state until after it is disposed in the formation, since this material tends to solidify only after a period of time. For this

reason, this plasticizing technique is relatively time consuming, and this is especially true if it is necessary to treat a plurality of locations in the same borehole. In fact, it is often necessary to wait several hours at one depth before the next section of the borehole can be isolated and treated.

Accordingly, it is desirable to deposit a quantity of gel or other liquid material adjacent the formation to keep borehole fluids from contaminating the treated formation. A material which has been found especially suitable for this purpose is a gel which is manufactured and sold by Oil Base, Inc. under the trademark "Black Magic."

SUMMARY OF INVENTION

These disadvantages of the prior art are overcome with the present invention, and novel methods and apparatus are provided for consolidating the matrix of an unconsolidated subsurface earth formation. More particularly, methods and apparatus are provided for isolating and perforating a section of the borehole sought to be completed, injecting a first liquid to clean debris out of the isolated section after perforation of the casing, displacing the first liquid from the isolated section by a second plastic liquid and injecting such second plastic liquid into said isolated and perforated formation, injecting a third liquid or semiliquid gel or other suitable substance into the isolated section to support the second liquid in the formation, and maintaining such gel on or adjacent said formation while isolating and perforating a second different section of the borehole and injecting preflush and plastic liquid therein.

Accordingly, it is an object of the present invention to provide methods and apparatus for consolidating two or more unconsolidated formations during a single trip through a borehole. It is also an object of the present invention to provide novel methods and apparatus for isolating, perforating, and consolidating an unconsolidated earth formation.

It is a further object of the present invention to provide methods and apparatus for completing an oil or gas well into an unconsolidated earth formation, and for injecting a plurality of different liquids, in a separated manner, into the well casing and into or adjacent the earth formation of interest.

It is a feature of the present invention to provide methods and means for maintaining a quantity of gel isolated in the casing from other fluids therein, and to shift such gel slidably to and about the perforated casing after injection of consolidating fluid.

It is another feature of the present invention to provide means and method for delivering separated flows of flushing and consolidating fluids, and the like, from the surface of the earth to a subsurface earth formation sought to be perforated and consolidated.

It is a further feature of the present invention to provide method and means for selectively aiming and discharging a casing perforator in a borehole.

It is another feature of the present invention to provide method and apparatus for selectively perforating a preselected subsurface earth formation, injecting a consolidating fluid into said perforated formation, and thereafter disposing a quantity of relatively inactive fluid adjacent said perforated formation to protect said consolidating fluid.

It is a further feature of the present invention to provide methods and means for selectively perforating and injecting consolidating fluid into a subsurface earth formation while simultaneously protecting consolidating fluid previously injected into that or another formation at a location adjacent thereto.

These and other objects and features of the present invention will become apparent from the following detailed description, wherein reference is made to the figures in the accompanying drawings.

IN THE DRAWINGS

FIG. 1 is a simplified pictorial representation, partly in cross section, of a section of a cased borehole traversing a fluid-

bearing earth formation of interest, and further illustrating the overall configuration of one form of apparatus embodying the concept of the present invention.

FIG. 2 is a more detailed cross-sectional representation of a selected portion of the apparatus illustrated in FIG. 1, and showing the apparatus in one condition.

FIG. 3 is a similar representation of the apparatus depicted in FIG. 2, but showing the apparatus in another different condition.

FIG. 4 is another representation of the apparatus depicted in FIGS. 2 and 3, but showing the apparatus in a further condition.

FIG. 5 is a cross-sectional representation of a different portion of the apparatus depicted in FIG. 1, and more particularly illustrating a device for separating two dissimilar liquids being conducted downhole through a string of tubing or the like.

FIG. 6 is a similar representation of the device illustrated in FIG. 5, but showing the device in a different condition.

FIG. 7 is a detailed cross-sectional representation of an alternate embodiment of the present invention which is different in form from the apparatus depicted in FIGS. 2-4.

FIG. 8 is a simplified cross-sectional representation of the orienting portion of the apparatus depicted in FIGS. 2-4.

FIG. 9 is a schematic representation of a detector device suitable for incorporation in a casing perforator and adapted to operate in conjunction with the orienting portion of the apparatus depicted in FIG. 8.

FIG. 10 is a simplified cross-sectional representation of an alternate form of a portion of the apparatus depicted in FIG. 7.

FIG. 11 is a simplified pictorial representation of another different apparatus embodying the concept of the present invention.

DETAILED DESCRIPTION

Referring now to FIG. 1, there may be seen a pictorial representation, partly in cross section, of the overall configuration of a system embodying the concept of the present invention. In particular, there may be seen a typical borehole 2 containing a conventional steel well casing 3 and traversing a representative fluid-bearing earth formation 4. The depicted system may be seen to include a sand consolidation assembly 12 suspended at the end of a string of pipe or tubing 5, and having rotatably interconnected upper and lower sections 13 and 14. A suitable perforator 11 having preferably a single shaped charge or bullet may be seen to be seated in the bottom of the lower section 14 of the assembly. As will hereinafter be apparent, the perforator 11 is preferably connected to the lower end of a conventional cable 7 having one or more conductors for transmitting electrical data and power between the assembly 12, and the surface of the earth.

The tubing 5 preferably extends to the surface to provide a conduit to supply liquids to the assembly 12, and a separating swab 6 may be slidably mounted on the cable 7 to maintain a separation between two different liquids as will hereinafter be explained in detail. Thus, the swab 6 travels down the cable 7 until it reaches the swab catcher 9 which may be located above an orientation assembly 10 mounted on the upper end of the upper section 13 of the assembly, and which may further be located below a bypass valve assembly 8 such as that depicted in U.S. Pat. No. 3,306,361. The swab 6 remains in the catcher 9, and the liquid above the swab 6 then flows past and into the assembly 12.

The upper and lower sections 13 and 14 are also interconnected to be moved longitudinally toward and from each other through a limited distance of travel. The upper section 13 includes an upper housing 19 with a pair of spaced-apart packer members 15 and 16, circumferentially mounted thereon, and a lower mandrel 23 slidably extending to the upper end of the lower section 14 of the assembly 12. As hereinafter explained in greater detail, the packer members 15 and 16 are preferably provided with outwardly flared edges formed of a resilient

material such as rubber, and arranged in confronting relationship to each other to slidably engage the interior surface of the casing 3. A gun port 18 may be provided in the side of the upper housing 19 between the packers 15 and 16. Although the cups 15 and 16 are normally slidable within the casing 3, they are also preferably sized and adapted so that their flared edges may be urged outwardly into fluidtight engagement with inside surface of the casing 3 when the pressure between the cups 15 and 16 is greater than the pressure in the wellbore.

As may also be seen, a third packer 17 may be positioned on the upper housing 19 below the middle packer 16 to provide an isolated annular space 22 for containing a quantity of gel or other suitable material.

The lower section 14 of the sand consolidation assembly 12 may be composed of a housing 24 adapted to slidably receive the lower end of the mandrel 23 and having a plurality of expandable anchors 20 located circumferentially about its outside surface for engaging the inside surface of the casing 3 in response to pressure within the assembly 12. The lower end of the housing 24 is preferably closed by a suitable end plug 25 having at least one bypass port 21 located in one side and positioned so as to be closed when the lower end of the mandrel 23 is driven fully into the lower housing 24 and end plug 25, as will hereinafter be explained in detail.

The bypass valve assembly 8 hereinbefore mentioned may be of any suitable design. However, it is particularly convenient to the present invention that the bypass valve assembly 8 be openable by raising the tubing 5 to draw the upper section 13 of the assembly 12 a limited distance upward from the lower section 14. Accordingly, the bypass valve 8 and the bypass port 21 are preferably both opened by raising the upper section 13, and closed by urging the upper section 13 downwardly so that the lower end of the mandrel 23 blocks the port 21 when the bypass valve 8 closes.

In practicing the present invention, the entire sand consolidation assembly 12 may be lowered through the casing 3, by means of suitable hoist (not depicted) located at the surface of the earth, until the assembly 12 is located at a preselected depth in the borehole 2. During downward travel of the assembly 12, both the bypass valve assembly 8 and the bypass port 21 will preferably be open to permit the well fluid normally present in the casing 3 to be displaced upwardly through the assembly 12 so as not to obstruct its downward movement through the well bore.

After the assembly 12 is properly located in the casing 3, a preflush of kerosene may be introduced into the assembly 12 by way of the tubing 5 to flush out accumulated well fluids. Subsequently, the upper section 13 may be raised so as to position the upper and middle packers 15 and 16 opposite the section of the casing 3 selected to be perforated, and to close the port 21 and bypass valve 8. Thereafter, the perforating gun 11 may be lowered into the assembly 12 by means of the cable 7, and seated in the lower section 14. Next, the pressure in the tubing 5 and assembly 12 may be raised above the hydrostatic pressure in the wellbore to expand the anchors 20 and the packers 15 and 16 against the inside surface of the casing 3, and once it is elevated, the upper section 13 may then be rotated by the tubing 5 independently of the lower section 14 until the orienting assembly 10 actuates suitable circuitry in the gun 11 to transmit a signal to the surface indicating that the gun port 18 is positioned opposite the charge of the gun 11. Thereafter, the gun 11 may be fired to perforate the casing 3 and the formation 4.

Next, additional kerosene or other suitable material may be introduced into the tubing 5 and to the perforated casing 3 and formation 4 to flush out debris resulting from perforation of the casing 3 and formation 4. Thereafter, a flow of liquid plastic, preferably separated from the kerosene by a swab 6, may be injected down the tubing 5 into the annulus between the packers 15 and 16, and through the perforated casing 3 and formation 4. The perforating gun 11 may then be withdrawn and reloaded without disturbing the assembly 12 and the plastic deposited in the formation 4, provided a pres-

sure greater than the formation pressure is maintained in the tubing 5 and assembly 12, and in the annulus between the packers 15 and 16.

It is desirable to keep the treated formation 4 isolated from contaminating wellbore fluids until the plastic has solidified therein, and this has previously been accomplished by keeping the consolidation equipment positioned adjacent the formation for many hours before shifting the equipment to another level to perforate the casing in a new location. In the apparatus depicted in FIG. 1, however, the annulus 22 between the middle and lower packers 16 and 17 may be loaded or filled with a gel or other suitable material capable of flowing through the perforation in the casing 3 and against the formation 4, but substantially incapable of displacing the plastic. Accordingly, the assembly 12 in FIG. 1 may be raised in the casing 3 to position the middle and lower packer cups 16 and 17 above and below the perforation in the casing 3, respectively, immediately after the plastic has been injected through the perforated casing 3 and into the formation 4, to enable the gel to protect the plastic therein. Thereafter, the perforating gun 11 may be removed and reloaded, and may then be returned to the assembly 12 for perforating the casing 3 at the new location isolated by the upper and middle packers 15 and 16.

Referring now to FIGS. 2-4, there may be seen a more detailed and cross-sectional representation of the sand consolidation assembly 12 depicted generally in FIG. 1. As hereinbefore explained, the overall assembly 12 is adapted to be suspended from the lower end of the tubing string 5, and is preferably provided with a suitable orientation assembly 10. As may be seen in FIGS. 2-4, the orientation assembly 10 may include a collar 51 fixedly and coaxially mounted in or adjacent the upper end of the assembly 12 and formed of non-magnetizable material. An insert 52 formed of a magnetizable material is mounted in one side of the inside circumference of the collar 51.

As may further be seen, the upper section 13 of the assembly 12 may include a mandrel 23 having a bearing flange 63 located along its length, and having a mandrel bypass port 71 suitably located in the lower end of the mandrel 23. A flared upper swab cup 53 formed of a suitable elastomer such as rubber, may be mounted in a downwardly directed position on an upper cup retainer portion 56 of the housing 19 above the lateral gun port 18, and a similar swab cup 54 may be seen to be mounted below the gun port 18, and in an upwardly directed manner, on a so-called middle cup retainer portion 57 of the housing 19. Accordingly, when the pressure within the mandrel 23 is raised above that of the hydrostatic pressure in the wellbore, the pressure within the annular space defined by these cups 53 and 54 will urge the rims of the cups 53 and 54 into fluidtight engagement with the inside wall of the casing 3.

As also illustrated in FIGS. 2-4, a suitable gel container or reservoir 59 may be suspended from the lower end or side of the middle cup retainer portion 57 of the housing 19, and another similar swab cup 55 may be supported on the lower end of the reservoir 59 in an upwardly flared manner by a lower cup retainer portion 58 of the upper housing 19. Thus, the middle and lower swab cups 54 and 55 provide means for holding a quantity of gel 79 or other suitable material as hereinbefore explained. The gel reservoir 59 may be provided with one or more ejection ports 62 in its upper end for permitting gel to flow from the inside of the reservoir 59 into the annulus defined by the cups 54 and 55. An annular piston 60 may be seen to be slidably disposed within the reservoir 59 above a plurality of pressure ports 61, whereby hydrostatic pressure in the wellbore will drive the piston 60 upwardly within the reservoir 59 to eject gel 79 into the annulus between the cups 54 and 55, gel from the reservoir 59 to replace gel flowing through the perforated casing 3 to the formation 4.

As hereinbefore stated, the lower section 14 of the assembly 12 may include a housing 24 which is slidably disposed about

the lower end of the mandrel 23 and which is formed at its upper end to provide a hollow bearing chamber 66. A suitable annular ball bearing assembly 64 may be disposed in the chamber 66 and positioned on the upper side of the bearing flange 63 of the mandrel 23. An inwardly directed shoulder 68 provides a stop for limiting downward travel of the mandrel 23 into the lower section 14, and a suitable O-ring gasket 67 may be included therein for insuring a gastight fit between the upper and lower sections 13 and 14 of the assembly 12. The lower end of the lower housing 24 may be closed with a suitable end plug 25 having a gun centralizing support 82 mounted coaxially therein. As illustrated, the bypass port 21 is located in the lower end of the housing 24, and shoulders 69 and 70 with O-rings 77 and 78 mounted therein, are provided within the housing 24, above and below the gun port 21, for restricting fluid flow through ports 21 and 71 when the mandrel port 71 is aligned with the bypass port 21. Accordingly, it may be seen that when the mandrel 23 is raised to position the port 71 above the O-ring 77, this will interrupt fluid flow through the bypass port 21 into the mandrel 23.

It is desirable that the upper and lower sections 13 and 14 be selectively rotatable as a unit as well as independently of each other. Further it is desirable to provide means for aligning the mandrel bypass port 71 with the bypass port 21 in the end plug 25. Accordingly, one or more splines 27 and 28 may be located on the outside surface of the mandrel 23 to engage the upper end of the bearing chamber 66 when the upper and lower sections 13 and 14 are urged together, and to disengage the bearing chamber 66 when the upper section is fully displaced from the lower section 14. The splines 27 and 28 are preferably aligned with the ports 21 and 71, and if two or more splines are provided as suggested by FIGS. 2-4, additional bypass ports 26 and 88 are preferably provided.

The anchor assembly 20 depicted in FIG. 1, may be composed of a circumferential array of individual anchor members 73 each mounted to be urged radially outwardly of the housing 24 by compression or inflation of a flexible or elastomeric diaphragm 74, and this inflation may be achieved by increasing the pressure within the mandrel 23. The pressure may be seen to be communicated to the diaphragm 74 through one or more pressure intake ports 76, to expand the diaphragm 74, and to thereby urge the anchor members 73 into gripping engagement with the inside of the casing 3. It should be noted, however, that pressure communication between the pressure chamber 75, and the pressure intake ports 76 and diaphragm 74, may only be had by way of the mandrel bypass ports 71 and 88. Accordingly, the anchor members 73 may only be engaged with the casing 3 when the mandrel bypass ports 71 and 88 are positioned above the O-ring 77, and into fluid communication with the annulus 72, whereby pressure or fluid communication through the bypass ports 21 and 26 is blocked.

As further illustrated in FIGS. 1-4, the depicted sand consolidation assembly 12 is adapted to be used with a monodirectional casing perforator 11 preferably having a single laterally directed bullet or shaped charge 85. The lower end of the perforator 11 may be adapted to be nonrotatably engaged with a centralizing support 82 located in the bottom of the end plug 25 when the perforator 11 is seated within the assembly 12. Thus, one or more splines 84 may be provided internally of the support 82 for fixedly engaging the end member 94 of the perforator 11, and thereby preventing the perforator 11 from being rotated within the lower section 14 of the sand consolidation assembly 12. A suitable exhaust port 83 may be located in the wall of the support 82, and adjacent the bottom of the end plug 25 to provide an outlet for liquids which would otherwise be trapped therein and prevent the end member 94 of the perforator 11 from being landed securely in the support 82.

The upper end of the perforator 11 may include a suitable detector 92 and positioning fin 93 for centralizing the perforator 11 within the mandrel 23, and for indicating when the port 18 is positioned in front of the bullet or charge 85. In the apparatus depicted in FIGS. 1-4, the detector 92 includes a

projecting sensor element or probe which cooperates with the positioning fin 93 to centralize the upper end of the perforator 11 within the assembly 12, and which is also adapted to scan the inside surface of the collar 51 during rotation of the upper section 13 and orientation assembly 10. Accordingly, when the magnetizable insert 52 is rotated to abutting engagement with the tip of the projecting sensor containing the detector 92, the detector 92 will generate an electrical signal which may be transmitted to the surface by way of the cable 7. Receipt of the signal at the surface may be taken as an indication that the port 18 is aligned with the charge 85 on the perforator 11, and that the perforator 11 may then be actuated.

As may be seen, the upper section 13 is interconnected with the lower section 14 through the bearing 64, the bearing flange 63, and the upper inside surface of the bearing chamber 66. Accordingly, the upper section 13 may be seen to be freely rotatably within the casing 3 independently of the lower section 14 of the assembly 12, when the mandrel 23 is raised far enough to lift the splines 27 and 28 completely out of the bearing chamber 66.

Referring again to FIG. 2, there may be seen an illustration of the relationship of the various components of the sand consolidation assembly 12 during and after the assembly 12 is thrust down the casing 3 at the end of the tubing string 5. More particularly, downward movement of the tubing string 5 and mandrel 23 through the casing 3 urges the bearing flange 63 against the shoulder 68, to thereby push the lower section 14 of the assembly 12 down the casing 3. During downward travel of the assembly 12 through the casing 3, the lower end of the mandrel 23 will be positioned adjacent the bottom of the lower housing 24 and end plug 25, and the bypass ports 21 and 26 will be aligned with the mandrel bypass ports 71 and 88 to permit any fluids trapped in the casing 3 below the lower rubber cup 55 and the lower section 14 of the assembly 12, to pass up through the mandrel 23 and tubing string 5, and to discharge through the open bypass valve assembly 8 depicted in FIG. 1. The pressure intake ports 76 will be closed, however, and thus the diaphragm 74 will be relaxed and the anchor members 73 will be disengaged from the inside surface of the casing 3.

Referring now to FIG. 3, it may be seen that the assembly 12 has been moved to a preselected depth in the borehole 2, and the mandrel 23 has been raised to arrange the cups 53 and 54 to isolate the section of the casing 3 sought to be perforated. The upper section 13 will, of course, be raised within the casing 3 without disturbing the lower section 14 until the bearing flange 63 lifts the bearing 64 high enough to engage the upper wall portion of the bearing chamber 66. The bypass ports 71 and 88 in the mandrel 23 are now moved to a position above the O-ring 77, and fluid communication through the bypass ports 21 and 26 in the end plug 25 will now be blocked. On the other hand, communication is now established between the interior of the tubing 5 and the annulus 72 and pressure injection ports 76 in the mandrel 23. After the pressure in the mandrel 23 is raised above the hydrostatic pressure in the wellbore, the perforator 11 may be lowered through the tubing string 5 and into the assembly 12 until the end member 94 is securely and fully seated in the support 82 centrally positioned in the bottom of the end plug 25. The pressure in the mandrel 23 may be supplied through the tubing string 5 to the interior of the mandrel 23, the diaphragm 76 should be kept expanded to keep the anchor members 73 in gripping engagement with the interior of the casing 3. The lower section 14 of the assembly 12 will now be held in a relatively nonrotatable position within the casing 3 during rotation of the upper section 13 to position the magnetic insert 52 immediately opposite the tip of the detector 92 located on the upper end of the perforator 11. Thus, the detector 92 indicates that the bullet or charge 85 is immediately confronted by the port 18, and the perforator 11 may then be fired to perforate the casing 3 and the adjacent earth formation 4 as illustrated in FIG. 3. After the casing 3 has been perforated, a suitable plastic or other consolidating material may be fed down the wellbore through the tubing

string 5, and into the mandrel 23, for ejection through the port 18 and the perforated casing 3, for injection into the earth formation 4.

Referring now to FIG. 4, there may be seen another pictorial representation of the assembly 12 previously depicted in FIGS. 2 and 3, and illustrating how the assembly 12 has been raised until the middle and lower cups 54 and 55 are now positioned above and below the perforated section of the casing 3 previously isolated by the upper and middle cups 53 and 54. Thus, the gel 79 carried between the cups 54 and 55 may now flow through the perforated casing 3 and against the formation 4 containing the previously injected plastic. The gel is not capable of flowing into the formation, however, and thus the gel will merely protect the plastic from contamination by the fluids in the wellbore until solidification. During this period, the perforator 11 may be reloaded and fired to perforate the casing 3 in the section now isolated by the upper and middle cups 53 and 54.

It will be noted that when some of the gel 79 held in the annulus between the cups 54 and 55 flows out of the perforated casing 3, this tends to decrease or deplete the amount of gel being held by the cups 54 and 55. However, this loss of gel will be replaced by a proportionate outflow of gel from the reservoir 59, since the hydrostatic pressure in the casing 3, and communicated to the piston 60 through the ports 61, will drive the piston 60 upward to force out gel through the port 62 and into the annulus between the cups 54 and 55 in an amount equal to the amount of gel expended through the perforated casing 3.

Referring now to FIGS. 5 and 6, there may be seen a detailed representation of the separating swab 6 depicted generally in FIG. 1. In particular, the swab 6 includes a longitudinal strength member 32, which is adapted to be slidably mounted on the cable 7 supporting the perforating gun 11, and which further includes an upper spring retainer 34 fixedly attached to the upper end of the strength member 32 and also adapted to slidably move along the cable 7. A lower spring retainer 35 is movably located along the lower end of the strength member 32, and a helical spring is positioned between the retainers 34 and 35 and about the strength member 32. A hollow rubber bulb or cup 36 may be disposed about the strength member 32 and spring 33, with its lower end fluid tightly interconnected with the lower spring retainer 35, and with its edges urged outwardly to sealing engagement with the tubing string 5 by means of two or more bow springs 37 and 38.

The strength member 32 may be provided with an annular latching groove 39 which is engageable by finger or tooth portions of each of a pair of latches 40 and 41 pivotally mounted on the lower spring retainer 35. As may be seen, the latches 40 and 41 are adapted to engage the groove 39, when the latches are positioned within the tubing string 5, and when the lower spring retainer 35 is positioned upward toward the upper spring retainer 34 so as to compress the spring 33, and so as to outwardly blow the bowsprings 37 and 38. However, as may be seen in FIG. 6, when the swab 6 is positioned in a section of tubing having a diameter larger than the diameter of the tubing string 5, the compressed spring 33 will drive the latches 40 and 41 to pivot outwardly from the latching groove 39, to disengage the lower spring retainer 35 from the strength member 32. The lower spring retainer 35 will then be shifted downwardly along the strength member 32 to permit the bowsprings 37 and 38 to relax the cup 36.

In order that two or more different fluids may be passed down the tubing string 5 without being commingled, the swab 6 may be inserted in the top of the tubing string 5 behind one fluid (such as the preflush) and ahead of another fluid (such as the plastic). When the swab 6 is inserted in the top of the tubing string 5, however, the latches 40 and 41 are positioned to engage the groove 39 and to compress the spring 33, and to arch the bowsprings 37 and 38. Accordingly, the expanded cup 36 will provide an effective seal between the two fluids as long as the swab 6 is within the tubing string 5. Moreover,

when the second liquid (such as the plastic) is injected into the top of the tubing 5 behind the swab 6, it may be utilized to drive the swab 6 downwardly through the tubing string 5 until the swab reaches the swab catcher 9.

The swab catcher 9 has a diameter larger than the diameter of the tubing string, however. Thus, when the swab 6 drops into the swab catcher 9, the latches 40 and 41 will each be pivotally shifted out of engagement with the groove 39 in the strength member 32, because of the compression in the spring 33. The spring 33 will then drive the lower spring retainer 35 down along the strength member 32, until the bow springs 37 and 38 and the cup 36 revert to their original normal shapes.

It may be noted that the swab catcher 9 depicted in FIGS. 5 and 6 may be provided at its upper end with a sloping shoulder configuration, and that the lower end of the strength member 32 has a diameter not greater than the diameter of the strength member 32 across the latching groove 39. Thus, if the relaxed swab 6 depicted in FIG. 6 is drawn upward into the tubing 5, the latches 40 and 41 will be urged together as they ride upward along the stopping portion of the catcher 9 until their teeth move into abutment with the narrower lower end of the strength member 32. In this position, the outer edges of the latches 40 and 41 will be sufficiently close together so that the swab 6 may enter the tubing string 5. Accordingly, after the perforator 11 has been fired and the various fluids have been injected through the perforated casing 3 and into or against the formation, the perforator 11 may be lifted out of the assembly 12 and tubing string 5, in order that it may be reloaded, and this will also carry the swabs 6 up to the surface where they may be reused.

Referring now to FIG. 7, there may be seen an alternative form of the sand consolidation assembly 100 having upper and lower sections 101 and 102 which are also rotatable independently of each other. A suitable orientation assembly 99 may be provided at the top of the upper section 101, and may include a nonmagnetizable collar 125 having a magnetizable insert 124, all as hereinbefore described in detail. The upper section 101 may be further seen to include upper and lower confronting rubber cups 117 and 118 mounted above and below a suitable gun port 119 located to accommodate a charge or bullet fired from a suitable monodirectional casing perforator 122. As illustrated, the perforator 122 is preferably provided with a detector 123 mounted at its upper end, and adapted to "see" the insert 124 which, of course, is longitudinally aligned with the gun port 119.

The upper section 101 includes a mandrel 103 having a flange 109 mounted or located at its lower end for supporting a suitable bearing assembly 108, and also for engaging the upper inside surface of the bearing housing portion 107 of the lower section 102 of the assembly 100.

The lower section 102 may be composed of a hollow member or sleeve 110 having the aforementioned bearing housing portion 107 located at its upper end, and having a plurality of anchors 104 mounted circumferentially thereon. An expandable diaphragm 105 may be included for urging the anchors 104 into engagement with the casing 3 in response to pressure supplied through the mandrel 103 and through a suitable pressure port or ports 106 in the sleeve 110. The lower end of the sleeve 110 is preferably closed by any suitable means. In the assembly 100 depicted in FIG. 7, however, an end plug 111 having splines 112 is provided for maintaining the perforator 122 in a nonrotatable manner relative to the lower section 102 of the assembly 100, as well as supporting the perforator 122 in a centralized manner within the assembly 100.

In this alternative embodiment of the invention, the bypass port 114 in the assembly 100 is closed by the perforator 122 in the end plug 111. Accordingly, the lower end of the perforator 122 is preferably enlarged and adapted to be slidably positioned within the lower end of the sleeve 110 and into the end plug 111, and O-rings 115 and 116 may be included to insure a fluidtight seal to close the bypass ports 114.

It will be apparent that it is necessary to vent any fluids which might be trapped within the end plug 111 below the end of the perforator 122. Accordingly, a passageway 113 is preferably included therein, to provide a pressure balance for the perforator 122 by permitting such fluids to flow upward into the sleeve 110.

Referring now to FIG. 8, there may be seen a simplified cross-sectional representation of the internal structure of the detector 123 and orientation assembly 99 represented in FIG. 7. In particular, the orientation assembly 99 may be composed of a concentrically mounted collar 125 formed of a nonmagnetizable material, and having a recess in one side. An insert 124, which is preferably formed of soft iron or some other suitable material is mounted in the recess so as to be flush with the inside circumference of the collar 125.

The perforator 122 is preferably centrally located within the collar 125 and the orientation assembly 99. However, the detector 123 illustrated as a projecting probe or sensor in FIG. 7, may be seen in FIG. 8 to include an electromagnet 130 having a generally horseshoelike configuration. As also illustrated in FIG. 8, the magnet 130 may be horizontally mounted within the probe. However, the magnet 130 may also be positioned vertically therein if desired.

Referring now to FIG. 9, there may be seen a simplified diagram of circuitry which may be incorporated in the perforator 122 for providing an indication of the proximity of the insert 124 depicted in FIG. 8, and including a suitable horseshoelike electromagnet 131, such as the magnet 130 depicted in FIG. 8, and having one end of its winding interconnected to a reference potential (the housing of the perforator 122), and having its other end interconnected through a capacitance 132 to a conductor 133 which is interconnected to the downhole end of the cable 91 depicted in FIG. 3. The conductor 133 may also be interconnected with the ignition circuitry in the perforator 122, which is represented in FIG. 9 by the winding and solenoid 134 and resistance 135.

Referring now to FIG. 10, there may be seen an alternative technique for opening and closing the bypass port in the lower end of sand consolidation apparatus. In particular, the lower end of the apparatus may be closed with an end plug 140 having oppositely located bypass ports 141 and 142 on each side thereof. The lower end of a perforator may be provided with a pair of spaced-apart annular enlargements or flanges adapted for slidable movement within the end plug 140, and suitable O-rings 143 and 144 are preferably included to provide a fluidtight seal between the adjacent surfaces of the gun and the end plug 140. A pair of laterally positioned pistons 146 and 147 are also preferably included in the end of the perforator between the two flanges or enlargements for the purpose of locking the end of the perforator to the end plug 140. As illustrated, the end of the perforator may be provided with a T-shaped passageway 139 having its crossbar portion located above the upper enlargement and O-ring 143, and having its shank or vertical portion extending through the bottom end of the perforator. Accordingly, when the perforator is seated in the end plug 140, any fluid accumulated in the end plug 140 below the ports 141 and 142 will be forced up through the passageway 139 and out into the end plug 140 above the upper O-ring 143.

It may be seen that after the lower end of the perforator is landed within the end plug 140, the upper O-ring blocks fluid flow through the bypass ports 141 and 142. Alternatively, the ports 141 and 142 will be open at all times except when the perforator is landed in the end plug 140. Thus, use of an assembly such as that depicted in FIG. 10, and also such as that depicted in FIG. 7, may eliminate the need for a bypass valve assembly 8 such as that represented in FIG. 1. The pistons 146 and 147 may be driven outwardly of each other and into locking engagement with the ports 141 and 142 by means of pressure within the passageway 139, to keep the perforator positioned within the end plug 140 when the perforator is fired. Although not specifically illustrated in FIG. 10, the pistons 146 and 147 may be spring loaded whereby they may

be retracted and disengaged from the ports 141 and 142 by releasing the pressure within the passageway 139.

Referring now to FIG. 11, there may be seen another form of sand consolidation assembly 153 slidably disposed within a casing 151 in a borehole 150 traversing an earth formation 152 sought to be treated. The assembly 153 may include upper and lower sections 157 and 159, and a suitable orientation assembly 160 located at the upper end of the upper section 157. A bypass port 156 may be located in the lower end of the lower section 159, and a pressure-actuated anchor assembly 158 may be included as hereinbefore described and depicted.

The upper section 157 may be provided with spaced-apart and downwardly directed rubber cups 161 and 162 located above a suitable gun port 165. A second lower pair of spaced-apart rubber cups 163 and 164 may be provided below the gun port 165, and thus the rubber cups 162 and 163 confronting each other provide means for isolating the section of the casing 151 intended to be perforated with the single charge 166 on the perforator 154. As depicted, the perforator 154 is suspended within the assembly 153 by a conventional cable 155.

The annular space 167 between the lower pair of cups 163 and 164 may be filled with gel or the like, as hereinbefore explained. However, it should also be noted that the annular space 168 may also be filled with gel, and thus the assembly 153 in FIG. 11 may be moved either direction in the casing 151, after the perforator 154 has been fired and the plastic liquid has been injected into the formation.

Although the plastic to be injected into the formation 4 has been referred to herein as though it is a single fluid, it should be clearly understood that the sand consolidation process may be carried by the sequential injection of two or more fluids which, when combined in the formation 4, interact with each other to provide a bonding material.

It will also be apparent that the structures described herein have been depicted in the accompanying drawings in a simplistic manner, and that many portions of a structural element, which has been depicted as a single component, will actually be a combination of two or more individual components. The threaded and bolted joints and the like, which will immediately be apparent to those with ordinary skill in this art, have been omitted from the drawings in order not to present detail which is immaterial to the invention.

It will further be apparent from the foregoing that various modifications and variations may be made in the structures and procedures described herein without substantial departure from the essential concepts of the present invention. Accordingly, it should be clearly understood that the forms of the invention described herein and depicted in the accompanying drawings, are exemplary only and are not intended as limitations on the scope of the present invention.

What I claim is:

1. A system for treating a subsurface earth formation traversed by a borehole containing a casing or the like, comprising

an elongated hollow body assembly for containing consolidating fluid and for receiving and longitudinally supporting a perforator, said body assembly having upper and lower rotatively coupled sections,

isolating means on said assembly for isolating a section of said casing for perforation by said perforator,

engaging means on said assembly for securing said lower section of said assembly within said casing independently of rotation of said upper section therein, and

supporting means on said assembly for cooperating with said casing for defining an isolated annular space in said casing for accommodating and supporting a quantity of relatively inactive protecting fluid adjacent but separated from said consolidating fluid

2. The system described in claim 1, wherein said isolating means includes

first and second resilient annular packing members spaced apart longitudinally along said upper section of said assembly and expandable into fluidtight engagement with the inside surface of said casing for isolating a selected section of the interior of said casing, and

wherein said supporting means includes a third resilient annular packing member spaced along said upper section from said first and second members and engaging the inside surface of said casing to define an annular space between said casing and said upper section for accommodating and supporting a quantity of said protecting fluid.

3. The system described in claim 2, further including reservoir means mounted on said assembly and communicating with said annular space where said annular space is defined in said casing by said third packing member and one of said first and second packing members, and said annular space contains a further reserve quantity of said protecting fluid.

4. The reservoir means described in claim 3, including an annular housing having an ejection port communicating with said annular space in said casing and a pressure port communicating with hydrostatic pressure in said casing, and

piston means disposed in said annular housing and slidably movable therein between said ejection and pressure port in response to said hydrostatic pressure for urging said protecting fluid in said annular housing through said ejection port into said annular space.

5. The system described in claim 4, further including a fourth resilient annular packer member on said assembly for defining another different annular space in said casing for supporting and containing another quantity of protecting fluid.

6. The system described in claim 5, wherein said body assembly includes rotatably and slidably interconnected upper and lower sections.

7. The system described in claim 6, wherein said first and second resilient members are mounted on said upper section of said body assembly, and

wherein said third resilient member is located on said upper section of said body assembly.

8. The system described in claim 7, wherein said upper section has a lateral port between said first and second resilient members through which said perforator may be discharged.

9. The system described in claim 8, further including orienting means functionally located in said upper section of said body assembly relative to said lateral port and cooperating with said perforator to provide an indication of alignment of said perforator with said port.

10. A system for treating a subsurface earth formation traversed by a borehole containing a well casing or the like, comprising

an elongated hollow body assembly for receiving and containing a formation treating fluid and for longitudinally supporting a perforator suspended from a cable, a perforator for producing a perforating force along a transverse perforating axis,

said body assembly having a rotatably mounted section for rotation relative to said perforator and including a laterally located port for alignment with said perforating axis,

isolating means on said body assembly for isolating the section of said casing confronted by said port, and

orienting means cooperating with said perforator for indicating alignment of said port in said body assembly with said perforating axis.

11. The system described in claim 10, wherein said perforator includes a sensing element mounted at a predetermined angular position relative to said perforating axis, wherein said orienting means including an activating element horizontally rotatable about said perforator for energizing said sensing element of said perforator, and

indicating means responsive to alignment of said gun port and said perforating axis of said perforator for generating an electrical signal.

12. The system described in claim 11, wherein said activating element of said orienting means includes a nonmagnetic collar mounted in the upper portion of said body assembly and rotatable horizontally therewith about said sensing element in said perforator, and

wherein said activating element further includes a magnet spaced in said collar at a predetermined angular relation with said gun port.

13. The system described in claim 12, wherein said sensing element includes a magnetically responsive probe for rotatably engaging the inside surface of said collar and actuating said indicating means when adjacent said magnet.

14. A system for treating a subsurface earth formation traversed by a borehole containing a well casing or the like, comprising

a tubing string adapted to be suspended in said casing to receive an input of consolidating liquid,

a hollow upper body member having its upper end fixedly interconnected with the lower end of said tubing string to receive consolidating liquid therefrom and further having a lateral port confronting the interior surface of said casing,

first and second flared annular resilient cup members mounted on said upper body member above and below said port for isolating a preselected section of said casing adjacent said formation,

annular fluid-containing means on said upper body member for slidable engagement with the interior surface of said casing to carry a gellike protecting liquid incapable of substantial permeation of the matrix of said earth formation,

a hollow lower body member rotatably interconnected with the lower end of said upper body member and adapted to releasably engage the interior surface of said casing, and a gun perforator interconnected with a cable extending upward through said tubing string and positioned against rotation within said upper and lower body members.

15. The system described in claim 14, further comprising swab means movably mounted on said cable and slidably and fluidtightly engaging the interior surface of said tubing string, and

swab retaining means fixedly secured in said tubing string above and proximate said upper body member for receiving and retaining said swab.

16. The swab means described in claim 15, further comprising

an elongated strength member longitudinally and slidably mounted on said cable,

a resilient member concentrically disposed about said strength member and normally smaller than the inside diameter of said tubing string, and

expansion means for longitudinally compressing said resilient member along said strength member to laterally expand said resilient member into slidable fluidtight engagement with said tubing string, and

latching means slidably compressed by said tubing string for releasably engaging said strength member to thereby releasably maintain said resilient member expanded laterally into engagement with the interior of said tubing string.

17. The system described in claim 16, wherein said swab retaining means comprises

a tubular housing interconnected between said tubing string and said upper body member and having a diameter larger than said tubing string and a lower shoulder portion for catching and supporting said swab therein.

18. A method of treating a subsurface earth formation traversed by a borehole containing a casing or the like, comprising

establishing a fluid flow path longitudinally through said casing between the mouth of said borehole and a selected section of said casing adjacent said formation, isolating said section of said casing from borehole fluids in said casing,

perforating said isolated section of said casing into said formation to couple said flow path to said formation,

injecting a flow of consolidating fluid down said flow path from the mouth of said borehole and through said perforated casing into said formation,

disposing an isolating fluid over the perforation in the casing and against but not substantially into said formation to protect said consolidating fluid in said formation while maintaining said isolating fluid separate from said borehole fluids in said casing.

19. The method described in claim 18, including the step of delivering a flow of flushing fluid from the mouth of said borehole down said flow path into and through said isolated and perforated section of said casing to said surface portions of said formation, and

said injecting step comprising thereafter delivering a flow of consolidating fluid from the mouth of said borehole and down said flow path into and through said isolated section of said casing to and into said formation to at least partially displace formation fluids therein.

20. The method described in claim 19, wherein said isolating fluid is a gellike semiliquid material.

21. The method described in claim 20, wherein said disposing step includes

injecting said isolating fluid from the mouth of said borehole and down said flow path to and through said perforated and isolated section of said casing after injection of said consolidating fluid, and

separating said isolating fluid from any consolidating fluid in said flow path.

22. A method of treating a subsurface earth formation traversed by a borehole containing a casing or the like, comprising

establishing and maintaining a quantity of gel in contact with said casing adjacent said formation and isolated from other fluids in said casing,

isolating a section of said casing opposite said formation and adjacent said quantity of gel,

selectively perforating said isolated section of said casing and opening a flow path into said formation,

injecting consolidating fluid through said flow path and into said formation, and

shifting said quantity of gel longitudinally along said casing and into said flow path in said formation to maintain said consolidating fluid in said formation, and

thereafter isolating and perforating another different section of said casing.

23. The method described in claim 22, further including maintaining said quantity of gel in said flow path in said formation during and after isolation and perforation of said another different section of said casing.

24. The method described in claim 23, wherein said establishing step further comprises

establishing a quantity of gel in two separate annular spaces each isolated in said casing from other fluid in said casing and respectively above and below the section of casing to be isolated and perforated and

said shifting step further comprises shifting one of said two annular spaces and the gel contained therein longitudinally along said casing to said isolated and perforated section thereof after injection of said consolidating fluid into said formation.

25. The method described in claim 22, wherein said injection step includes

establishing a fluid flow path longitudinally through said casing between the mouth of said borehole and said isolated section of said casing, and

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injecting said consolidating fluid through said fluid flow path in said casing to and through said isolated and perforated section of said casing into said formation to at least partially displace formation fluids therein.

26. The method described in claim 25, wherein said shifting step includes

isolating said gel and said flow path in said formation from said fluid flow path in said casing before isolating and perforating said another different section of said casing.

27. The method described in claim 25 wherein the injection steps includes the steps of

prior to injecting the consolidating fluid, injecting a flow of flushing fluid from the mouth of said borehole and down said fluid flow path in said casing to and through said isolated and perforated section of said casing to said flow path in and to said surface portions of said formation adjacent said borehole, and

wherein the thereafter injected consolidating fluid is supplied from the mouth of said borehole and down said fluid flow path in said casing to and through said isolated and perforated section of said casing and through said flow path in said formation to and into said formation.

28. Apparatus adapted for treating earth formations traversed by a cased wellbore and comprising:

a pipe string adapted to be disposed in such a wellbore;

a tubular body connected to said pipe string and having an interior space communicating therewith;

a perforator adapted for passage through said pipe string

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disposed in said interior space;

packing means on said body adapted for isolating a wall of a well casing to be perforated when said perforator is positioned in said interior space and actuated to establish fluid communication through such an isolated wall for introducing treating fluids into earth formations therebehind through said pipe string; and

means on said body cooperable with such a well casing and adapted for carrying a supply of fluent protective substances exterior of said interior space for introduction into such earth formations upon subsequent movement of said body along such a perforated casing wall to protect treating fluids previously introduced into such earth formations.

29. The apparatus of claim 28, wherein said perforator is dependently suspended in said pipe string by a cable having electrical conductor means and further including:

means for providing fluid communication between said packing means including a lateral port in said body adapted to be in alignment with the perforating axis of said perforator whenever said perforator is properly positioned within said interior space; and

signalling means on said body and said perforator coupled to said electrical conductor means and operatively arranged to provide a characteristic surface indication only when said perforating axis is aligned with said lateral port.

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