March 25, 1969 J. B. MERRITT 3,434,539

PLUGS FOR USE IN TREATING WELLS WITH LIQUIDS

Filed March 6, 1967

Sheet 1 of 2

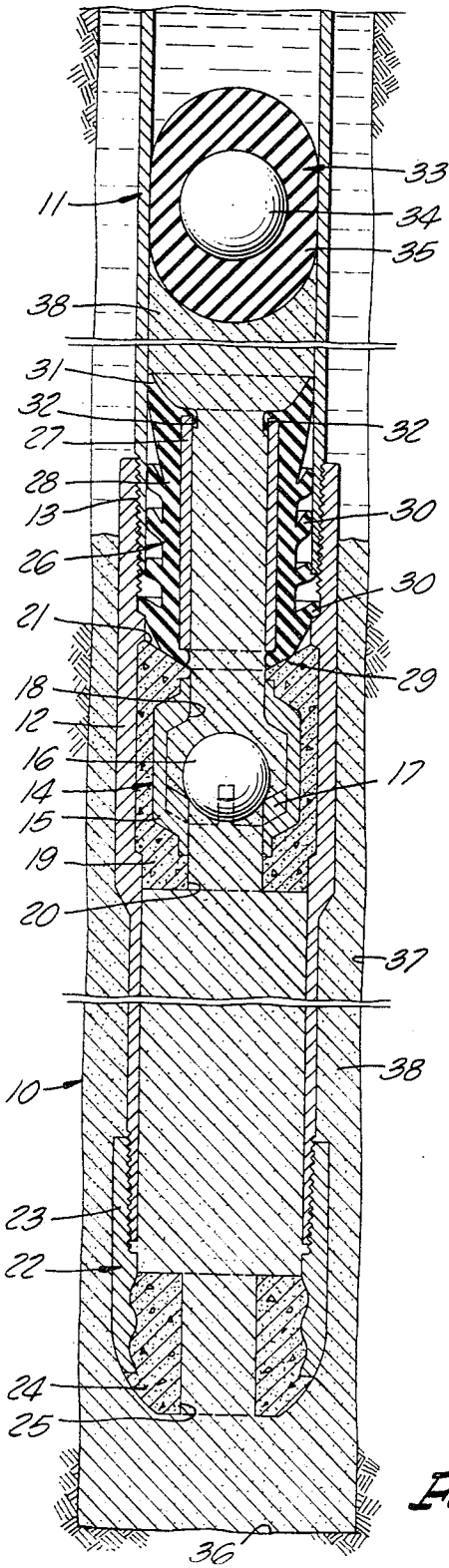


FIG. 1.

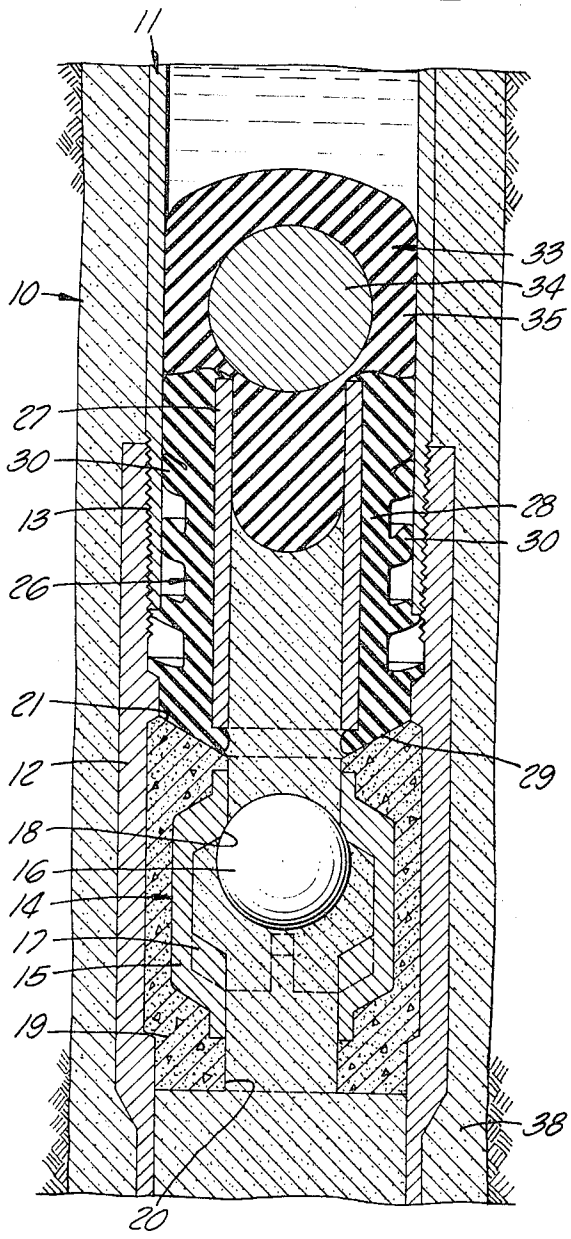


FIG. 2.

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PLUGS FOR USE IN TREATING WELLS WITH LIQUIDS

Filed March 6, 1967 Sheet 2 of 2

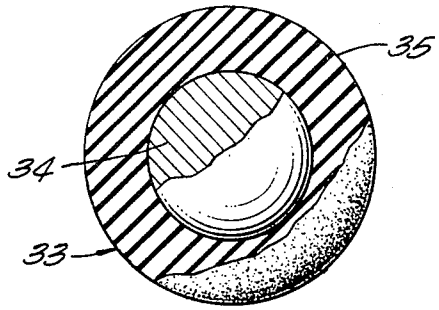


FIG. 3.

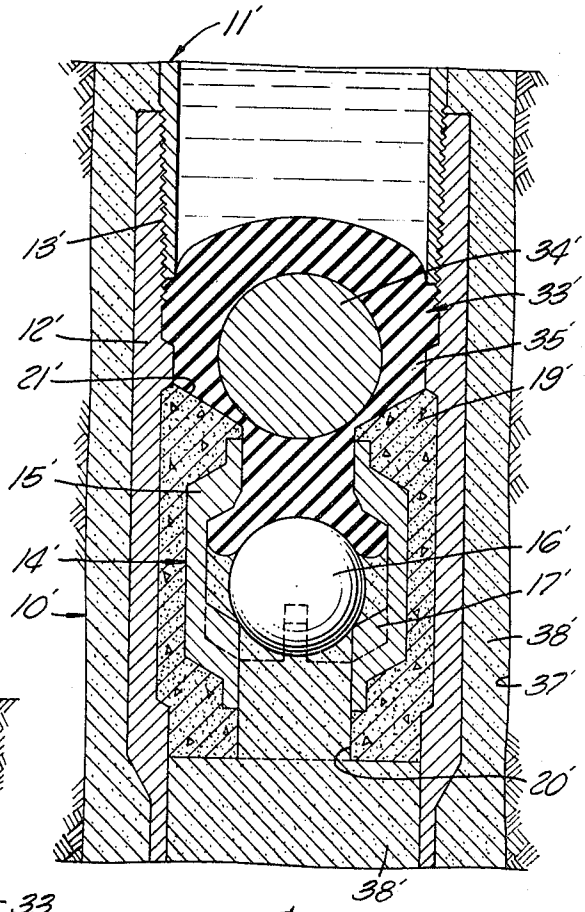


FIG. 5.

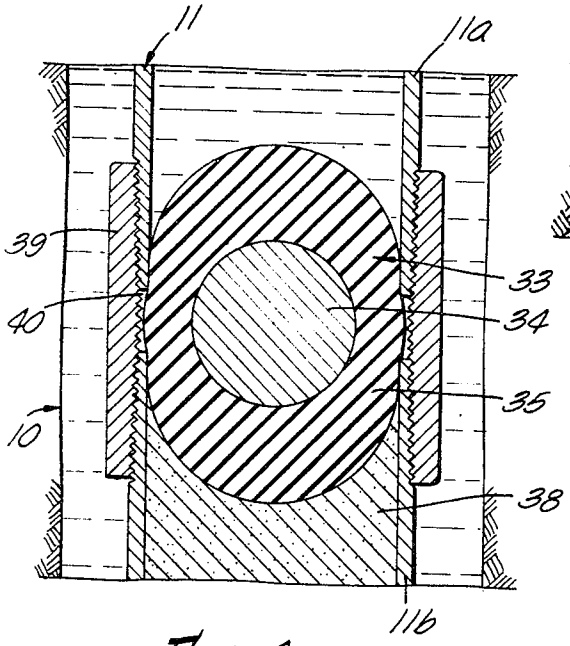


FIG. 4.

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United States Patent Office 3,434,539
Patented Mar. 25, 1969

3,434,539

PLUGS FOR USE IN TREATING WELLS WITH LIQUIDS

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Int. Cl. E21b 33/16
U.S. Cl. 166—153 9 Claims

ABSTRACT OF THE DISCLOSURE

A top plug having a rigid, spherical core surrounded by a concentric, resilient shell separates an underlying column of well treating liquid, such as cement grout, from an overlying column of pumped fluid in a well casing. A collar member, either formed as a part of the casing or provided by a bottom cementing plug, has a passage for discharging the treating liquid from the casing into the well bore. After the liquid has been displaced, the top plug closes this passage and stalls the pump. The top plug is non-extrudible through the passage.

BACKGROUND OF THE INVENTION

Field of the invention

This invention relates to apparatus for treating a well with a liquid, as in the cementing of wells, such as oil, gas and water wells. The invention is particularly concerned with a cementing plug or plugs inserted in the well casing for segregating the treating liquid or cement grout from other fluids in the casing.

DESCRIPTION OF THE PRIOR ART

U.S. Patent No. 1,647,003, issued Oct. 25, 1927, F. W. Huber, "Well Cementing," discloses a float of narrower diameter than the casing that floats between a column of cement grout in the casing and the higher mud fluid column above the cement grout. The float is shown as being spherical and is adapted to close the discharge opening in the shoe at the bottom of the casing. This float, being smaller in diameter than the bore of the casing, does not provide a seal with the casing wall, and being made of wood is not well adapted to effectively close the opening in the shoe.

U.S. Patent No. 3,100,534, issued Aug. 13, 1963, L. J. Herndon, Jr., et al., "Plug for Use in Conduits," shows two elongate cementing plugs made entirely, or in large part, of a resilient material, such as rubber. Each of the plugs is vertically oriented in its travel through the casing so that a single band around the upper portion of the plug receives considerable wear from rubbing against the casing wall. Although a relatively hard insert, such as a metallic insert, may be provided at the bottom of the plug, this insert may prevent proper seating of the plug on the flange in the casing and the plug may not seal against the flange. Such improper seating is most likely to occur when the periphery of the guiding flange is worn and the plug becomes canted in the casing. Without the insert, the plug, due to its resiliency, may be pumped through the flange.

Generally-cylindrical cementing plugs are commonly used in cementing wells. Depending upon their particular construction, they may be subject to some or all of the foregoing problems, or they may have their own characteristic problems.

SUMMARY

An object of the invention is to provide cementing apparatus that is an improvement over the cementing apparatus of the foregoing prior art.

Another object of the invention is to provide cementing apparatus including a top cementing plug that effectively isolates cement grout or the like from another fluid immediately thereabove.

Another object is to provide cementing apparatus including a top cementing plug that will travel through great lengths of casing without suffering undue wear.

Still another object is to provide in such apparatus a top cementing plug that will securely seal a discharge opening in a casing shoe or the like without regard to the orientation of the plug in the casing.

Another object is to provide a cementing plug or the like that cleanly wipes the inside surface of the casing through which it is run.

Yet another object is to provide in such apparatus a top cementing plug that cannot be pumped or extruded through the discharge opening.

Another object is to provide a pair of cementing plugs that cooperate to accomplish the foregoing objects.

These, and other objects, aims and advantages of the invention are realized in a plug for use in treating a well having a pipe disposed longitudinally in its bore and the pipe having an annular collar member positioned transversely therein and fixed against downward movement, the collar member having a central opening therethrough of smaller diameter than the inside diameter of the pipe and adapted to pass treating liquid from the pipe into the well bore, the plug comprising a body in the form of a sphere, the body having an outer resilient shell and an inner, rigid core concentric with and embedded in the body, the body having an outside diameter greater than the inside diameter of the pipe, the core being of such size as to permit the body, without regard to its orientation, to be laterally compressed and inserted into the pipe, to be moved downwardly through the pipe in response to hydraulic pressure above the body while sealing liquid above and below the body, to seat upon and conform to the collar member to seal the central opening against flow of liquid therethrough, and to prevent passage of the body through the central opening of the collar member in response to hydraulic pressure applied to the top of the body when it is seated on the collar member.

The collar member referred to in the immediately preceding paragraph may take a variety of forms. For example, it may be in the form of an internal flange in the casing. The collar member may also be provided by a bottom cementing plug, as will be described more fully hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an axial sectional view of a portion of a well having disposed therein cementing equipment including one form of the invention, the view illustrating the disposition of parts during displacement of the cement grout;

FIG. 2 is an axial sectional view, on a larger scale than FIG. 1, of a portion of the apparatus of FIG. 1 showing the disposition of parts following completion of grout displacement;

FIG. 3 is a view, partly in central section, of the top cementing plug of the apparatus shown in FIGS. 1 and 2, the plug being shown apart from the rest of the apparatus, the figure being on the same scale as FIG. 2;

FIG. 4 is a view, on the same scale as FIGS. 2 and 3, of a portion of the well above that shown in FIG. 2, and illustrating the top cementing plug in its passage between coupled lengths of well casing; and

FIG. 5 is an axial sectional view, on the same scale as FIGS. 2 to 4, of a portion of a well having disposed therein cementing equipment according to another form of the invention, the view illustrating disposition of the parts following completion of grout displacement.

DESCRIPTION OF PREFERRED EMBODIMENTS

The embodiment of FIGS. 1 to 4

Referring to FIGS. 1 to 4, there is shown a well, for example an oil well, designated by the general reference numeral **10**. Suspended in the well bore is a well casing **11**. A float shoe **12** is joined to the bottom of the casing **11** by a threaded connection **13**. A float valve assembly **14** is provided in the float shoe, the valve assembly having a valve cage **15** containing a valve ball **16**. The cage has ribs **17** that support the ball **16** in a lower or valve-open position, and a seat **18** that is engaged by the ball in an upper or valve-closed position. The valve cage **15** is mounted in an annular, cured concrete body **19**. The float valve assembly has a fluid passage **20** extending axially therethrough. A frusto-conical cementing plug seat **21** is provided at the top of the concrete body **19**.

Threaded to the bottom of the float shoe **12** is a bull-nose **22** consisting of a sleeve **23** that carries a cured concrete ring **24** having a vertical, fluid passage **25** extending through it.

The floating equipment thus far described is conventional and generally widely known in the field to which the invention pertains; therefore, it need not be herein described in greater detail. The method of operating this equipment to float the casing into the well bore to the position shown in FIG. 1 is also conventional and generally widely known; hence it need not be described herein.

In FIGS. 1 and 2, a bottom cementing plug **26** is shown as being seated on the plug seat **21**. This plug has a central, tubular core **27** made of a rigid material, such as aluminum, bronze or brass. Molded around the core is an annular body **28** of resilient material, such as rubber, Neoprene, or the like. This annular body is formed with a frusto-conical bottom surface **29** adapted to mate with and seal against the cementing plug seat **21**. Projecting laterally from and forming a part of the annular body **28** is a plurality of outwardly and upwardly extending packer rings **30**. The top **31** of the annular body is cup-shaped. It will be understood that the diameter of the packer rings **30** and the cup-shaped top **31** of the annular body **28**, in its relaxed state when removed from the casing, is somewhat greater than the inside diameter of the casing **11**. As seen in FIG. 1, the packer rings and the cup-shaped top are laterally compressed by the casing wall, thereby to provide a fluid seal with the casing.

Shown at **32, 32** are tabs of a rubber diaphragm that has been ruptured. Originally, the diaphragm extended completely across the top opening of the tubular core **27**, closing this opening. The diaphragm was integral with the annular body **28** of rubber and, being relatively thin, was ruptured by fluid pressure from above after the bottom plug was seated on the seat **21**. Prior to rupture of the diaphragm, the bottom plug was pumped down the casing to the position shown in FIG. 1.

In accordance with the invention, a top cementing plug **33** is provided. Referring to FIG. 3, this plug is shown removed from the well casing. The plug **33** has a rigid core **34**, in the form of a solid sphere, that is made of aluminum, brass, bronze or other hard material. Such other material includes cured synthetic resin, such as phenol-formaldehyde resin, commonly known by the trademark Bakelite. Preferably the material of the core is easily drillable so that it may be drilled out by the well drilling equipment, if desired. The core **34** may be solid, as shown, or it may be hollow.

The plug **33** also has a resilient, outer shell **35** in the form of a hollow sphere that is concentric with the core **34**. The outer shell is made of a cured mechanical rubber composition of medium hardness. The shell preferably has a Shore A durometer hardness of 65, which is about the same as the hardness of an automobile tire tread. However, the hardness of the shell is not critical and, for practical purposes, may fall within the range of from about 50 to about 75, as tested by the Shore A durometer. The shell **35** is preferably bonded to the core **34** throughout the spherical interface between the two components by the employment of any well known bonding cement.

From the foregoing description, methods of making the plug **33** will be apparent to those persons skilled in the rubber molding art.

As seen in FIG. 1, the top plug **33** is shown disposed in the casing **11**. The resilient outer shell **35** is laterally compressed and confined by the wall of the casing. The shell, being unconfined above and below the plug, expands vertically in both directions to assume a vertically elongated shape, the bond between the shell and the core preventing separation of the shell from the core at the top and the bottom. It will be understood that the terms "top" and "bottom" are merely relative, as the normal spherical shape of the plug is distorted into the elongated shape shown in FIG. 1, no matter in what orientation the plug is disposed in the casing. The plug **33** seals against the casing wall and prevents intermixing of liquids in the casing above and below the plug, whether the plug is at rest or in motion down the casing.

In an actual embodiment of the invention, the inside diameter of the casing **11** is 4⅞", the inside diameter of the tubular core **27** of the bottom plug **26** is 2⅛", the diameter of the rigid core **34** of the top plug is 3¼", and the outside diameter of the undistorted shell **35** is 5¾". The core **34** is a solid sphere of cured phenol-formaldehyde resin composition. The shell is a hollow sphere of cured rubber having a Shore A durometer hardness of 65.

The core **34** must be smaller than the inside diameter of the casing and larger than the top opening of the tubular core **27**. Conveniently, the inside diameter of the tubular core **27** is about 0.44 times the inside diameter of the the casing **11**, the diameter of the spherical core **34** is about two-thirds the inside diameter of the casing, and the outside diameter of the undistorted shell **35** is about 1.2 times the inside diameter of the casing.

The foregoing exemplary dimensions and dimensional ratios are not critical. In general, the outside diameter of the shell of the top plug may be from about 1.1 to about 1.4 times the inside diameter of the casing, the diameter of the spherical core may be from about 0.5 to about 0.75 times the inside diameter of the casing, and the inside diameter of the tubular core of the bottom plug may be from about 0.5 to about 0.8 times the diameter of the spherical core.

The operation of the apparatus will now be described, by way of example, with reference to its use in cementing a well. The casing **11**, with its float shoe **12** and bull-nose **22** attached, is lowered into the well to the position shown in FIG. 1, the bull-nose being spaced above the bottom **36** of the well. The annulus **37**, between the casing together with its floating equipment and the wall of the well, is ordinarily full of drilling mud. This mud is removed from the annulus by pumping preflush fluid down the casing, out through the bull-nose passage **25**, and up the annulus to displace the mud through the top of the annulus. The bottom plug **26**, with its diaphragm **32, 32** intact, is then inserted in the top of the casing on top of the column of liquid in the casing. Cement grout is next pumped into the casing to force the bottom plug and the liquid therebelow down the casing. When the required volume of cement grout has been pumped into the casing, the top plug **33** is inserted in the casing above and in

contact with the top of the column of cement grout. Thereafter, a liquid, such as water, is pumped into the top of the casing to drive the top plug down the casing. The top plug moves the cement grout, the bottom plug, and the liquid below the bottom plug down the casing. Of course, the liquid below the bottom plug flows out of the passage **25** and is displaced up the annulus.

When the bottom plug **26** is arrested against the seat **21** of the floating equipment, continued operation of the pump causes the cement grout to burst the diaphragm **32, 32** of the bottom plug, whereupon the cement grout **38** flows through the tubular core **27** of the bottom plug, through the floating equipment, out of the passage **25** in the bull-nose, and up the annulus **37**. This is the stage of the operation depicted in FIG. 1.

Continued pumping drives the top plug **33** into contact with the bottom plug **26** to displace substantially all of the cement grout into the annulus **37**. As shown in FIG. 2, the pressure of the liquid above the top plug **33** forces the latter into tight sealing engagement with the bottom plug **26** and with the casing wall immediately thereabove. The pump stalls, it being unable to force additional liquid into the top of the casing. The stalling of the pump indicates that no more cement grout can be displaced into the annulus.

Pressure is maintained above the top plug until the cement grout has set to bond the casing to the wall of the well. If desired, the top and bottom plugs, the float valve assembly, and the cured concrete ring **24** can then be drilled out of the pipe.

The top plug, in its travel down the casing, rolls and wallows, yet maintains a good seal with the casing wall. Such action distributes the wear on the outer surface of the plug more or less uniformly over the entire surface of the plug.

The seating and sealing of the top plug with the bottom plug, as seen in FIG. 2, is independent of the orientation of the top plug. Because of the extreme distortability of the shell **35**, a tight seal with the bottom plug is attained, even though the latter may be canted out of axial alignment with the casing. It is observed in FIG. 2 that the resilient shell of the top plug **33** is so distorted by the pressure thereabove that a portion of the shell is forced into the bore of the tubular core **27** to close the bore, that another portion is in tight sealing engagement with the interior of the top of the annular body of rubber of the lower plug, and that the side of the top plug is expanded outwardly to seal against the wall of the casing immediately above the bottom plug.

The top plug **33** maintains a tight seal with the casing as it traverses the gaps between adjacent sections of casing. Referring to FIG. 4, an upper section **11*a*** of the casing **11** is joined to a lower section **11*b*** by a threaded coupling **39**. A gap **40** exists between the opposed ends of the two casing sections. In 5½" A.P.I. casing the gap is about 1" in height. A top plug for this size casing is so proportioned that the plug is in contact with the wall of the casing over a cylindrical area having a height of about 2". Thus, in traversing the gap **40**, the plug **33** never has less than an aggregate of about 1" of its vertical extent in circumferential contact with the inner wall of the adjacent casing sections **11*a*** and **11*b***, and this is enough to provide adequate sealing of fluids above and below the plug. For other sizes of pipe, the height of the area of the top plug that is in contact with the wall of the pipe can be estimated using geometrical principles, or the height can be empirically determined. The size relationships given hereinbefore will usually provide a top plug that will satisfactorily bridge the gaps between adjacent sections of commonly used casing.

The embodiment of FIG. 5

In cementing a well with the apparatus of the present invention, the bottom plug may be dispensed with, and the top plug allowed to seal directly against the seat provided in the floating equipment.

In FIG. 5, the components of the apparatus shown therein and that correspond to like components of the apparatus of FIGS. 1 to 4 are designated by corresponding primed reference numerals.

Referring to FIG. 5, a well **10'** has disposed therein a casing **11'** having appended thereto floating equipment, including a float shoe **12'**. The float shoe has a float valve assembly **14'** mounted in a cured concrete body **19'**, the body having a frusto-conical seat **21'** at its top. A plug **33'**, which in its undistorted condition has the form of a composite sphere like the plug **33** shown in FIG. 3, is seated on the seat **21'** and subjected to the high pressure of the column of liquid above the plug. The resilient spherical shell **35'** is distorted to provide a dependent portion that projects into the valve cage **15'** in tight sealing engagement therewith, another frusto-conical portion firmly engaging the seat **21'**, and a lateral portion pressed into sealing contact with interior portions of the shoe **12'** that are superjacent to the seat **21'**. The rigid spherical core **34'**, having a somewhat larger diameter than the diameter of the central opening provided by the cured concrete body **19'** adjacent to the seat **21'**, prevents the plug **33'** from being entirely extruded through this central opening.

The apparatus of FIG. 5, which omits a bottom plug, is used in substantially the same way as the apparatus of FIGS. 1 to 4. When the bottom plug is dispensed with, the bottom of the column of cement grout is in direct contact with the top of the column of liquid therebelow. If the densities of the two liquids are about the same, and if the pumping rate is not too high, the cement grout and the liquid ahead of it will not intermix to any great extent. Under these conditions, the use of a bottom plug is not essential.

The construction, functions and mode of operation of the plug **34'** are essentially the same as the construction, functions and mode of operation of the plug **34**, as set forth in the foregoing description of the embodiment of FIGS. 1 to 4, with the difference that the plug **34'** comes to rest against the seat **21'** instead of against the top of the bottom plug. In the present embodiment, the size of the rigid core **34'** is related to the size of the central opening in the seat **21'** in the same way that the size of the rigid core **34** is related to the size of the central opening in the bottom plug **14** of the embodiment of FIGS. 1 to 4.

The spherical plug of the present invention, owing to the extent of the area in contact with the interior wall of the casing and the pressure with which the resilient shell is urged against the wall, wipes the wall clean. Thus, substantially all of the cement grout is removed from the walls of the casing and carried into the well annulus. Moreover, as shown in FIG. 4, the outer shell bulges into the gaps **40** between the casing ends at the points of coupling and displaces most of the cement grout from the gaps.

The term "liquid" as used herein is intended to mean a fluid that acts as a liquid, whether or not it contains particles in suspension, as does cement grout. The term "collar member" is intended to mean any member that provides a seat for the spherical plug of the invention; the bottom plug **26** of the embodiment of FIGS. 1 to 4 or the cured concrete body **19'** of the embodiment of FIG. 5 are typical examples of such collar members.

The invention is not to be considered as limited to the specific embodiments shown and described herein, since these are to be regarded as illustrative rather than restrictive.

I claim:

1. A plug for use in treating a well with a liquid, the well having a pipe disposed longitudinally in its bore and the pipe having an annular collar member positioned

transversely therein and fixed against downward movement, said collar member having a central opening therethrough of smaller diameter than the inside diameter of the pipe and adapted to pass treating liquid from the pipe into the well bore, said plug comprising a body in the form of a sphere, said body having an outer resilient shell and an inner, spherical rigid core concentric with and embedded in said body, said body having an outside diameter greater than the inside diameter of said pipe, said core having a diameter smaller than the inside diameter of said pipe and being of such size as to permit said body, in any orientation, to be laterally compressed and inserted into said pipe, to be moved downwardly through said pipe in response to hydraulic pressure above said body while sealing liquid above and below said body, to seat upon and conform to said collar member to seal said central opening against flow of liquid therethrough, and to prevent passage of said body through said central opening in response to hydraulic pressure applied to the top of said body when it is seated on said collar member.

2. A plug for use in treating a well with a liquid, the well having a pipe disposed longitudinally in its bore and the pipe having an annular collar member positioned transversely therein and fixed against downward movement, said collar member having a central opening therethrough of smaller diameter than the inside diameter of the pipe and adapted to pass treating liquid from the pipe into the well bore, said plug comprising a body in the form of a sphere, said body including an outer, resilient, spherical shell of elastomeric material, and a rigid sphere concentric with and embedded in said shell, said shell having an outside diameter greater than the inside diameter of said pipe, said rigid sphere having a diameter smaller than the inside diameter of said pipe and larger than the diameter of the central opening through said collar member, said plug, in any orientation, being insertable in said pipe and, in response to fluid pressure applied to the top of said plug, being movable downwardly through said pipe into contact with said collar member, said resilient shell being laterally compressible by the wall of said pipe to seal liquid above and below said plug and being adapted to seat upon and conform to said collar member to seal the central opening thereof against flow of liquid through said opening, said rigid sphere being adapted to prevent passage of said plug through said central opening in response to hydraulic pressure applied to the top of the plug when it is seated on said collar member.

3. A plug as defined in claim 2 wherein the outside diameter of said shell is from about 1.1 to about 1.4 times the inside diameter of said pipe, the diameter of said rigid sphere is from about 0.5 to about 0.75 times the inside diameter of said pipe, and the diameter of the central opening through said collar member is from about 0.5 to about 0.8 times the diameter of said rigid sphere.

4. A plug as defined in claim 2 wherein the outside diameter of said shell is about 1.2 times the inside diameter of said pipe, the diameter of said rigid sphere is about 0.66 times the inside diameter of said pipe, and the diameter of the central opening through said collar member is about 0.66 times the diameter of said rigid sphere.

5. A plug as defined in claim 2 wherein said shell is bonded to said rigid sphere.

6. A plug as defined in claim 2 wherein said shell consists essentially of a mechanical rubber material having a Shore A durometer hardness of from about 50 to about 75.

7. A plug as defined in claim 2 wherein said rigid sphere is formed of a phenol-formaldehyde synthetic resin material.

8. Apparatus for treating a well with a liquid including:

(a) a pipe disposed longitudinally in the well bore;

(b) an annular collar member positioned transversely in the pipe and fixed against downward movement, said collar member providing a central opening therethrough adapted to pass liquid from the pipe into the well bore; and

(c) a plug in said pipe above said collar, said plug being positionable at the top of a column of liquid in the pipe and adapted to be hydraulically forced down the pipe to displace the liquid down the pipe and through said central opening;

wherein the improvement comprises:

said plug comprising a body in the form of a sphere, said body including an outer, resilient, spherical shell of elastomeric material, and a rigid sphere concentric with and embedded in said shell, said shell having an outside diameter greater than the inside diameter of said pipe, said rigid sphere having a diameter smaller than the inside diameter of said pipe and larger than the diameter of the central opening through said collar member, said plug, in any orientation and in response to fluid pressure applied to the top of said plug, being movable downwardly through said pipe into contact with said collar member, said resilient shell being laterally compressed by the wall of said pipe to seal liquid above and below said plug and being adapted to seat upon and conform to said collar member to seal the central opening thereof against flow of liquid through said opening, said rigid sphere being adapted to prevent passage of said plug through said central opening in response to hydraulic pressure applied to the top of the plug when it is seated on said collar member.

9. A pair of plugs for use in treating a well with a liquid comprising:

(a) a bottom plug adapted to be hydraulically moved down the bore of a well pipe by the pressure of fluid above the plug, to be arrested against a stop member in the pipe, and to prevent the flow of fluid downwarly between the plug and the wall of the well pipe,

(i) a rigid, tubular core in said plug providing a central passage through the plug for the flow of fluid from above the plug to below the plug when the plug is arrested against the stop member, and

(ii) means normally closing said central passage and responsive to fluid pressure above the plug when said plug is arrested against the stop member for opening said passage; and

(b) a top plug adapted to be inserted in the bore of the well pipe above said bottom plug and to be hydraulically moved down the bore of the well pipe by the pressure of fluid above the top plug, to be arrested against said bottom plug, and to close the central passage of said tubular core thereby to prevent the flow of fluid downwardly therethrough;

wherein the improvement comprises:

said top plug comprising a body in the form of a sphere, said body including an outer, resilient, spherical shell of elastomeric material, and a rigid sphere concentric with and embedded in said shell, said shell having an outside diameter greater than the inside diameter of said pipe, said rigid sphere having a diameter smaller than the inside diameter of said pipe and larger than the diameter of said central passage, said rigid sphere being adapted, in any orientation of said top plug, to prevent said top plug from being extruded entirely through said central passage in response to hydraulic pressure applied to the top of said top plug when it is seated on said bottom plug and the latter is arrested against said stop member.

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U.S. Cl. X.R.

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