

[54] **APPARATUS AND METHOD FOR
RELEASING DIFFERENTIALLY STUCK
PIPE** 2,865,454 12/1958 Richards..... 166/301
3,082,825 3/1963 Hanner, Sr..... 166/202
3,263,307 2/1966 Brown..... 166/301

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La. *Primary Examiner*—Stephen J. Novosad
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[57] **ABSTRACT**

[21] Appl. No.: 263,502

Pipe stuck in a well by pressure differential sticking is recovered by swabbing the well to reduce pressure around the point of differential sticking and then exerting an upward pull on the stuck pipe. The method is practiced with an apparatus comprising a swabbing tool connected to a well jar or bumper sub.

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[51] Int. Cl..... E21b 31/02
[58] Field of Search..... 166/301, 73, 98,
166/99, 142, 152, 179, 202, 226, 240, 177, 178

[56] **References Cited**

UNITED STATES PATENTS

17 Claims, 5 Drawing Figures

2,190,442 2/1940 Costello..... 166/152 X

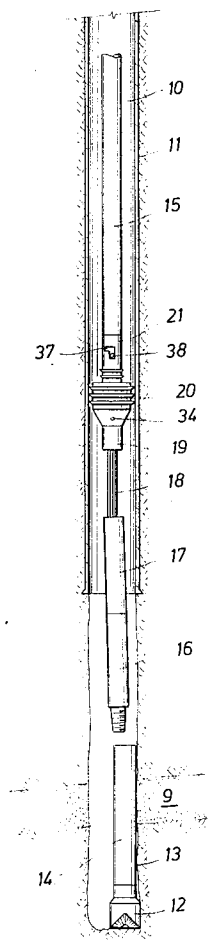


FIG. 1

FIG. 2

FIG. 3

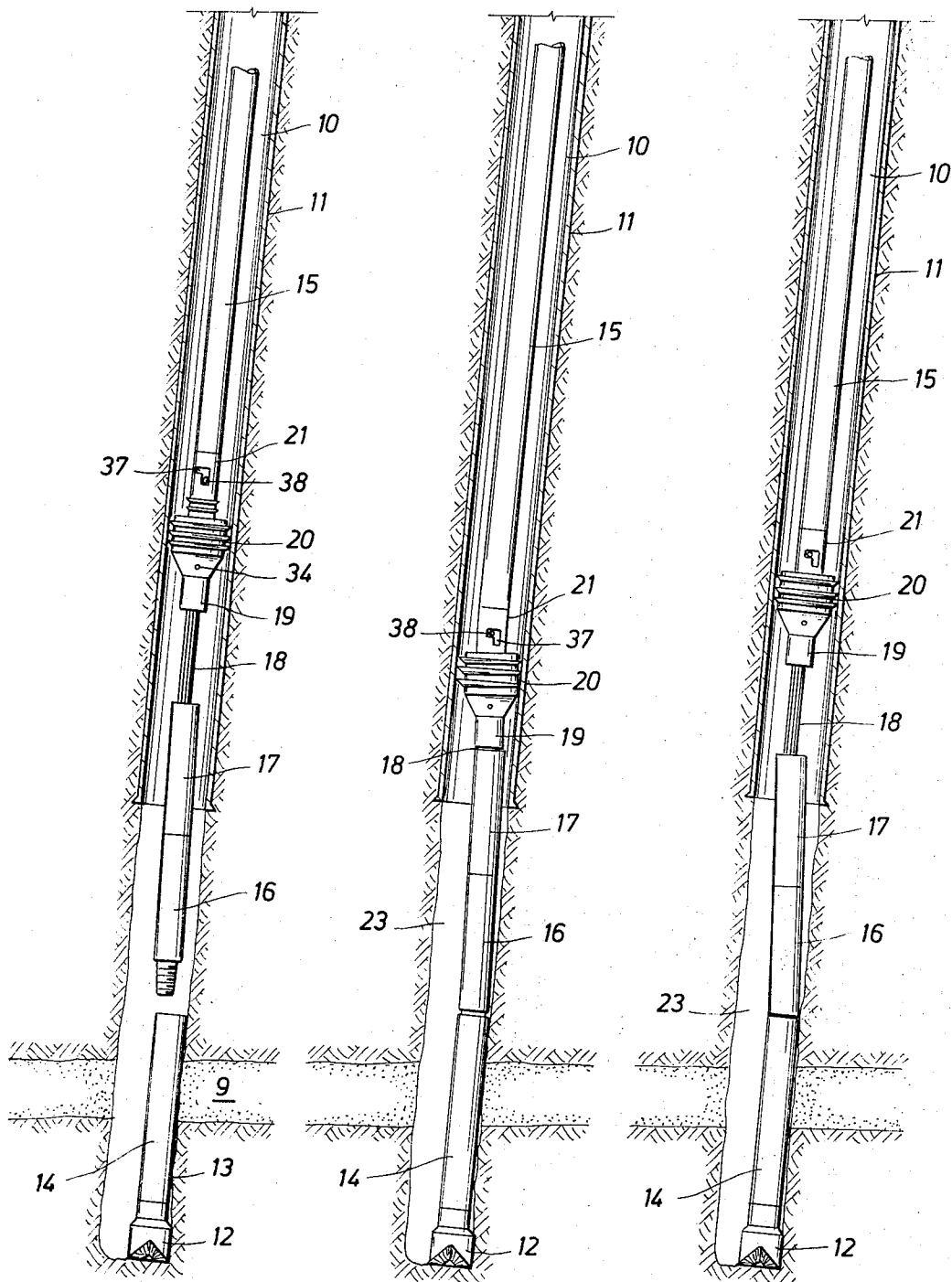


FIG. 4

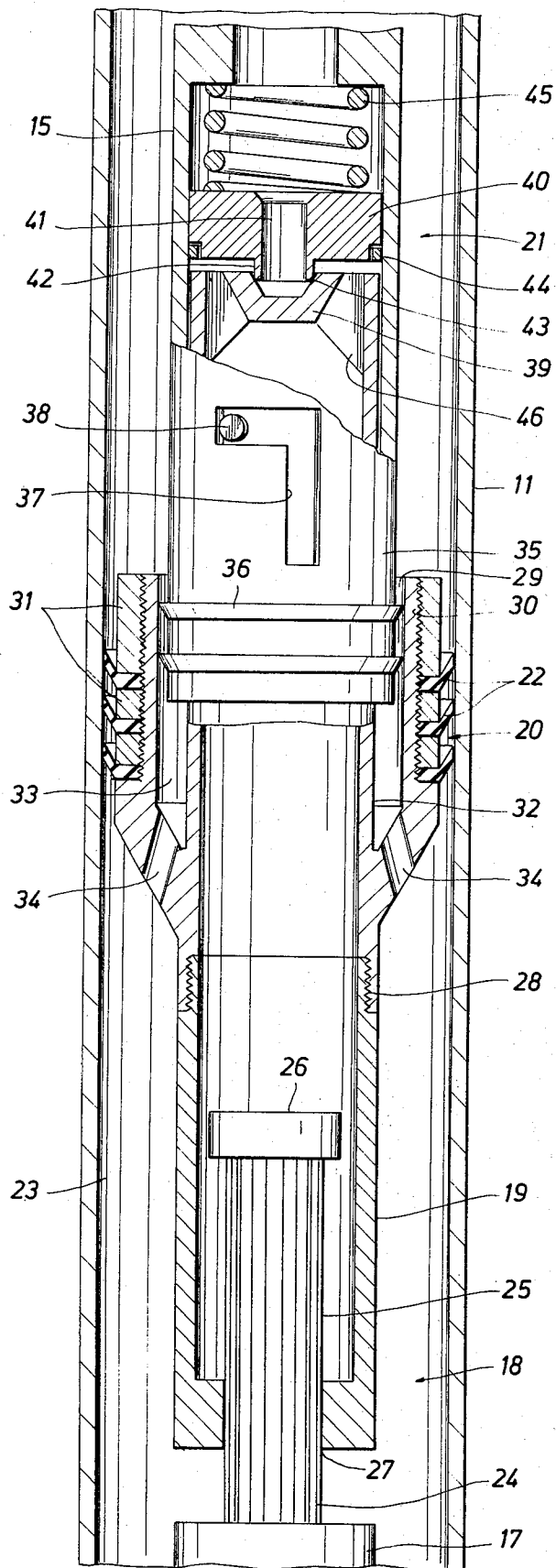
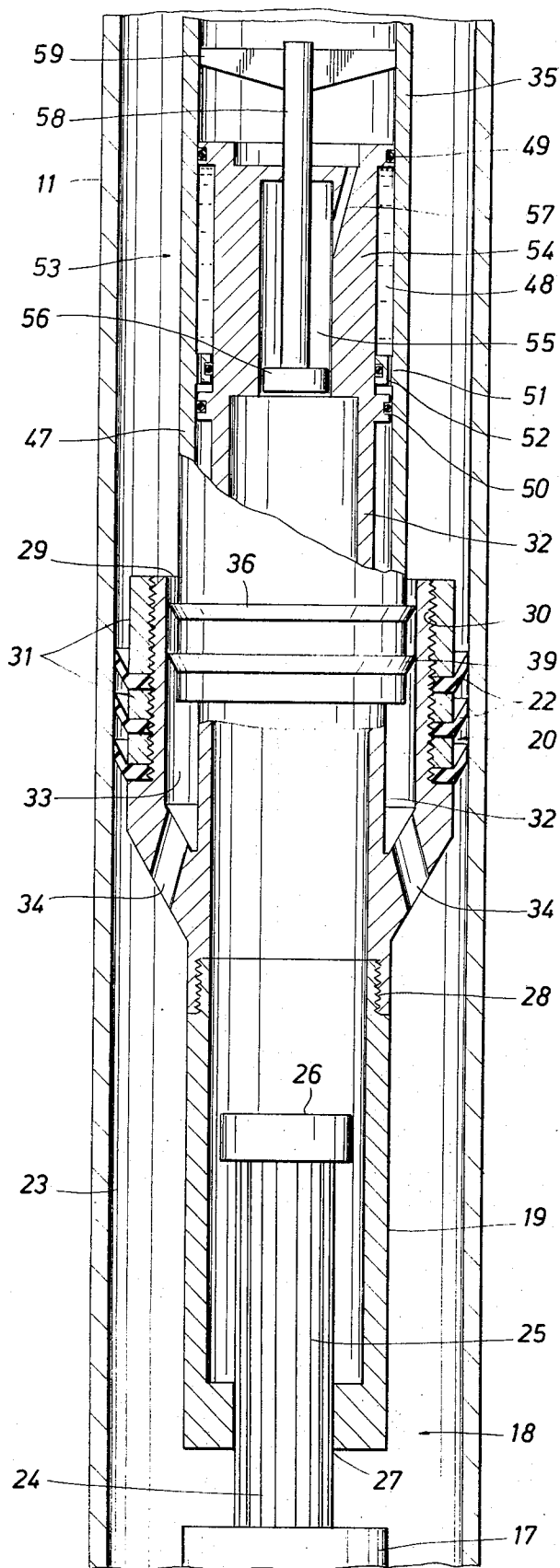


FIG. 5



APPARATUS AND METHOD FOR RELEASING DIFFERENTIALLY STUCK PIPE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention pertains to method and apparatus for carrying out fishing operations in a well borehole and relates, more particularly, to method and apparatus for freeing and recovering pipe stuck in a borehole due to a pressure differential between the hydrostatic pressure of fluid in the borehole and fluid pressure in a formation traversed by the borehole.

2. Description of the Prior Art

Pressure differentials between well borehole fluid, usually drilling mud, and formation fluids have been recognized as a major source and mechanism responsible for pipe sticking in wells for a number of years. See, e.g., W. E. Helmick and A. J. Longley, "Pressure-Differential Sticking of Drill Pipe and How It Can Be Avoided or Relieved" *Drilling and Production Practice*, (API) 1957). This type of sticking usually occurs in wellshaving a high differential between the fluid column in the well borehole and formation pressure where the drill pipe has been allowed to come to rest against the side of the hole. The pipe is "locked" against the side of the hole by the high fluid pressure within the well. Such sticking occurs in both slanted and substantially vertical boreholes; however slanted, directionally drilled holes are more susceptible than are straight holes.

The force resulting from the high fluid pressure differential across the stuck pipe is often so great that conventional fishing methods such as oil spotting and jarring may be ineffective in attempting to free the stuck pipe or "fish." It then becomes necessary to wash over, or drill around the stuck pipe. Both of these procedures require large amounts of drilling time and are, therefore, quite expensive.

U. S. Pats. Nos. 2,865,454 and 3,236,307 teach methods for freeing differentially stuck pipe. The former patent is directed to using a drill stem test tool to reduce the effective height of the fluid column contacting the fish and thereby reduce the pressure differential across the point of sticking. The latter patent is directed to method and apparatus for imparting a strong jarring force to the differentially stuck pipe to free it which involves a reduction in the density of at least part of the drilling mud column in the well.

Neither of these methods has proven entirely successful in all cases. Each has the disadvantage of requiring substantial reduction of the fluid pressure head in either the working string or the annular space surrounding that string. This increases the chances of incurring well control problems while attempting to recover the fish.

SUMMARY OF THE INVENTION

It has now been discovered that differentially stuck pipe may be freed from a well borehole without significantly reducing either the length or the density of fluid in the column of fluid in either the work pipe string or the annulus around that string by a method which comprises the steps of packing off a compressed-liquid filled portion of the borehole adjacent the stuck pipe; expanding the compressed liquid in the packed-off portion of the borehole while maintaining the head of fluid in the borehole above the packed-off portion of the

borehole substantially constant; and then exerting an upwardly directed force on the stuck pipe while maintaining the liquid in the packed-off portion of the borehole in the expanded condition.

The step of packing off the borehole advantageously comprises packing off a borehole portion of variable volume. Fluid in the packed-off portion of the borehole is then expanded by increasing the volume of this variable volume packed-off portion while preventing the movement of fluid into the packed-off portion of the borehole from portions of the borehole above the packed-off portion. In a preferred embodiment the step of packing off a borehole portion of variable volume comprises positioning a swab means in the borehole. The volume of the variable volume packed-off portion is then increased by moving the swab means upwardly in the borehole.

In another embodiment the step of expanding compressed liquid in the packed-off portion of the borehole comprises pumping fluid out of the packed-off portion of the borehole while maintaining the volume of that packed-off portion substantially constant.

Apparatus particularly suited for the practice of this method comprises a pipe string carrying fishing tool means for engaging a length of pipe stuck in a well borehole by differential sticking. The pipe string carries variable volume pack-off means for packing off a portion of the well borehole adjacent the length of stuck pipe, means for increasing the volume of the packed-off portion of the well borehole from an original volume to a greater volume, and means for exerting an upwardly directed force on the fishing tool means and the length of pipe when the volume of the packed-off portion of the well bore has been increased to the greater volume.

A preferred embodiment of a tool positionable in a pipe string for the practice of this invention comprises a telescoping connecting member, such as a bumper sub, including a bottom portion and a top portion telescopically connected for longitudinal movement between a closed position and a fully expanded position. Pack-off means is provided for closing the borehole to fluid flow above the stuck pipe. The pack-off means includes moveable pack-off means, such as a swab operatively connected to the top portion of the telescoping connecting member for swabbing the packed-off portion of the borehole to increase the volume thereof (and thereby reduce the pressure in the borehole adjacent the stuck pipe) as the top portion of the telescoping connection is moved upwardly. Means are provided for operatively connecting the top portion of the telescoping connecting member to a string of pipe and the bottom portion of the telescoping connecting member to the stuck pipe or to appropriate fishing tools for engaging the stuck pipe.

Advantageously, the pack-off means also comprises means for selectively opening and closing a by-pass around the swab means so that fluid circulation may be maintained in the well as the device is lowered into the hole and so that after the differentially stuck pipe has been freed, the pressure differential across the swab may be released and the fishing string withdrawn without swabbing the entire well.

In operation, the apparatus is positioned in the well disposed in a fishing string of drill pipe which is connected to the differentially stuck pipe or fish. The telescoping connecting member is placed in its closed posi-

tion. The pack-off means is set in the well above the telescoping connection; and then the top portion of the telescoping connection and the attached swab means are lifted by raising the drill string until the telescoping connection is in its fully expanded condition. This upward movement of the swab increases the volume of the packed-off portion of the borehole opposite the fish allowing compressed liquid in the borehole to expand with a consequent reduction in pressure. Thereafter, the drilling string is raised further to place substantial upwardly directed stress on the differentially stuck pipe. This upwardly directed force frees the fish since the pressure differential has been eliminated or reduced.

In some cases it may be desirable to run the apparatus of this invention in combination with a conventional hydraulic jar positioned above the telescoping connecting member so that an impulse may be transmitted to the stuck drill pipe after the pressure around that pipe is reduced by swabbing to further insure freeing of the stuck pipe.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a sectional view of the lower portion of a partially cased borehole showing an embodiment of the apparatus of this invention being lowered in the borehole to retrieve a section of drill string stuck by differential pressure sticking.

FIG. 2 is a view of the apparatus of FIG. 1 positioned to recover the stuck drill string section by the method of this invention.

FIG. 3 is a view of the apparatus of FIG. 1 as it is lifted in the borehole to reduce borehole pressure adjacent the stuck drill string section.

FIG. 4 is a vertical sectional view of a portion of the apparatus of FIGS. 1-3. FIG. 5 is another embodiment of the apparatus of FIG. 4.

DESCRIPTION OF A PREFERRED EMBODIMENT

Referring to FIG. 1, we see a well borehole 10, the upper part of which has been cased with tubular casing 11. The borehole 10 is filled with a liquid such as drilling mud. In the lower portion of the borehole 10 a portion of a drill string, in this case consisting of a drilling bit 12 and a length of drill collars 13 (hereinafter referred to as the fish 14), has been stuck adjacent a permeable earth formation 9 by differential sticking due to a high pressure differential between drilling mud in the borehole 10 adjacent the formation 9 and fluids in formation 9. The original drill string has been unscrewed from fish 14 in a conventional manner and withdrawn from the borehole 10 to be provided at the surface with tools for retrieving the fish 14.

FIG. 1 shows a pipe string 15 being lowered into the borehole carrying suitable equipment for retrieving the fish 14 according to the method of this invention. Lowermost on the string 15 is a fishing tool, such as conventional pipe spear 16, for engaging or otherwise latching onto the fish 14. The spear 16 is connected to the bottom portion 17 of a telescoping connecting member such as bumper sub 18. The upper portion 19 of the bumper sub 18 is operatively connected to a swab means 20. The bumper sub 18, swab means 20 and spear 16 preferably are all provided with interior passages for fluid flow so that drilling mud or other fluid may be continuously circulated down the pipe string 15, out the bottom of spear 16 and up the well in the

annular space surrounding the pipe string 15. Flow through the pipe string 15 is regulated by valve means 21 which may be selectively opened and closed as hereinafter described.

To retrieve the fish 14, the spear is set down on the fish 14 and connected thereto. At this point the bumper sub 18 is closed and the swab 20 preferably is positioned within casing 11 (FIG. 2). The valve 21 is closed so that no fluid may flow through pipe 15. The pipe string 15 is then lifted at the surface. This causes the swab 20 to pack-off a portion 23 of borehole 10 adjacent fish 14. Lifting of pipe string 15 is continued until the bumper sub 18 is fully expanded (FIG. 3). This expansion of the bumper sub 18 increases the volume of the packed-off portion 23 of the borehole 10 by an amount substantially equal to the volume of fluid displaced as the swab 20 is raised.

The drilling mud in the borehole 10 (which usually comprises a suspension of finely divided mineral matter in a liquid such as water) though often treated as being incompressible, is actually a compressible liquid with elastic properties. For example, the compressibility of water at borehole conditions of temperature and pressure is on the order of 2.5×10^{-6} /psi. This water has a bulk modulus of 400,000 psi. The latter figure implies that a pressure increase of 400,000 psi is required to decrease the volume of a given sample of water by 100 percent or viewed in another way and looking at smaller change, if the volume of a given sample of compressed water is increased by 10% there will be a corresponding 40,000 psi decrease in the pressure on that water. Thus, a relatively small percentage increase in the volume of a given sample of compressed water can result in a substantial decrease in the pressure on that sample.

Since the swab 20 and valve 21 seal the Packed-off portion 23 of the borehole 10 from fluid flow from above, fluid in the packed-off portion 23 of the borehole 10 expands to fill the increased volume of the packed-off portion 23 as the swab 20 and valve 21 are raised. This causes a reduction of pressure in the packed-off borehole portion 23 adjacent the fish 14. The magnitude of the pressure change may be determined from the following equation (assuming that no fluid flows into the packed-off portion 23 from surrounding formations):

$B = -V_1(P_2 - P_1)/(V_2 - V_1)$, where B is the bulk modulus of the fluid in the borehole portion 23, P_1 and P_2 are the pressures in the portion 23 before and after the change, and V_1 and V_2 are the volumes of the packed-off portion 23 before and after the jar is expanded.

As stated above, for water under downhole temperature and pressure, the bulk modulus is about 400,000 psi. In a 7% casing containing mud of density 15.2 pounds per gallon, for an original volume of the packed-off portion 23 of 450 cubic feet, the change in pressure for each 1 foot stroke of the swab 20 is on the order of 200 pounds per square inch. Thus, if the full stroke of the bumper sub 18 is 10 feet, pressure in the packed-off portion is reduced as much as 2,000 psi without any significant reduction in well control since the height of the fluid column in the well above the swab 20 is changed only by 10 feet. This pressure drop is equivalent to a reduction in length of a vertical col-

umn of 15.2 ppg mud (gradient 0.52 psi/ft) of about 2,000 feet.

The pressure drop in the borehole portion 23 as the bumper sub is raised can be regulated by changing the stroke of bumper sub 18, the displacement of the swab 20 and valve 21, or the original volume of the packed-off portion 23. Advantageously, these parameters are adjusted to provide a pressure drop about equal to the pressure overbalance between the drilling liquid in the borehole 10 adjacent formation 9 and the pressure of fluids within the formation 9. However, it should be appreciated that pressure in the borehole 10 preferably should not be reduced below the bubble point of the drilling liquid at borehole temperature. Once the pressure goes below the bubble point, gas which has a much higher compressibility than the liquid is evolved from solution. After gas is present small percentage changes in volume will no longer have dramatic effect on the pressure of the liquid.

After the bumper sub 18 is fully expanded, further upward movement of the drill string 15 exerts an upward axial force on the fish 14. This force in combination with the reduction of the differential sticking forces due to the reduced pressure in the packed-off portion 23 of the borehole 10 is usually sufficient to free the fish 14. Withdrawal of the string 15 is then continued.

Valve 21 is preferably opened as soon as possible after the fish 14 is free so that swabbing of the cell does not continue. Additional swabbing can lead to well control problems. Advantageously, valve 21 is of a type which can be opened without stopping the withdrawal of the drill string 10, for example by twisting the drill string. It is best to keep the fish 14 moving for as great a distance as possible after it is freed since a prime cause of differential sticking is allowing pipe to sit motionless in the borehole 10. If the fish 14 is kept in motion the chances of it sticking once more are greatly reduced.

Referring to FIG. 4 we see a more detailed view of an embodiment of the apparatus of this invention. The tool comprises a bumper sub portion which may be a conventional mechanical jar. For example, the bumper sub 18 may comprise a bottom portion 17 fixedly connected by welds or other means to a shaft 24 which is provided with a number of splines 25. A top portion 19 is slideably connected to the shaft 24. The top portion of the bumper sub 18 is preferably provided with a grooved opening 27 which meshingly engages the splines 25 of shaft 24 to transmit rotation of the top portion 19 of the sub to the bottom portion 17. Stop means for restricting the downward motion of the bottom part 17 of the bumper sub with respect to the top part 19 are operatively connected to the shaft 24. For example a head portion 26 of diameter greater than the diameter of the grooved opening 27 may be affixed to the shaft 24. When this head 26 abuts against the bottom of bumper sub portion 19, the bumper sub is in its fully expanded mode. Further upward motion of the top portion 19 will result in the transmission of an upwardly directed force to the bottom portion 17 of the bumper sub 18. The stroke of the jar 18 is preferably about 10 feet. However, bumper subs of greater or lesser stroke may be used depending upon the change in volume desired when the swab is lifted.

The bumper sub 18 is connected by suitable means such as threaded connection 28 to moveable pack-off

means, such as a swab 20, suitable for swabbing the well borehole 10 to increase the volume of the packed-off portion 23 of the borehole below the swab 20. In the embodiment of FIG. 4 the moveable pack-off is designed to swab casing 11. There the swab 20 provides efficient means for packing off the annular space between the casing 11 and the pipe string 15 to isolate the portion 23 of the borehole 10 adjacent the fish. However, in other embodiments a conventional packer may be used to close the borehole 10 outside the pipe string 15. In such a case, a swab (not shown) can be operated within a string of pipe such as string 15 to swab a portion of the interior of the string, in a manner similar to that discussed below with respect to casing 11, to reduce pressure opposite the fish.

The swab 20 of FIG. 4 comprises at least one, and preferably three or more, swab cups 22 formed from flexible material such as rubber. The cups 22 are positioned about the circumference of an externally threaded collar 30 and may be held in position by suitable means such as threaded spacer rings 31 which may be screwed on to the externally threaded collar 30. The cups 22 preferably have the shape of cones positioned with their smaller diameter below their larger diameter so that when the collar 30 is passing downwardly through the casing 11 the cones may flex inwardly to allow some fluid to leak between the cups and the casing 11. When the collar 30 is drawn upwardly through the casing 11 the cups 22 flex outwardly into sealing engagement with the interior wall of the casing 11.

The collar 30 is affixed at its lower end, below the swab cups 22, to a central first tubular member 32 of external diameter less than the internal diameter of the collar 30. The collar 30 is co-axial with the tubular member 32. In horizontal section (not shown) the collar 30 and tubular member 32 define concentric circles separated by an annular space 33 which is open at the top 29 of the collar 30 and closed at the bottom of the collar 30 by welds or other means for affixing collar 30 to the tubular member 32. (In the embodiment of the Figures the collar and the tubular member are formed from a single piece of steel).

The collar 30 is provided below the swab cups 22 with at least one by-pass port 34 for permitting fluid to flow between the annular space 33 and points in the borehole external of the collar 30 and below the packer cups 22. These by-pass ports 34 provide means for allowing the packer 20 to be raised and lowered in the borehole 10 without creating substantial pressure drop across the swab 20.

A second tubular member 35 of diameter intermediate that of the first member 32 and the threaded collar 30 is mounted on the first tubular member 32 for sliding longitudinal movement co-axial with tubular member 32. This second tubular member 35 carries at least one external sealing means such as rubber sealing member 36 for sealing engaging the interior wall of the externally threaded collar 30 to close the annular space 33 to fluid flow from above the swab cups 20 when the second tubular member 35 is slid downwardly on first tubular member 32.

Means are provided for restricting the motion of the second tubular member 35 with respect to the first tubular member 32 between an uppermost position in which the rubber sealing members 36 are not in engagement with the interior walls of the collar 30 and a lowermost sealing position in which the rubber mem-

bers 36 are in such sealing position (e.g., the position illustrated in FIG. 2). In the embodiment of FIGS. 1-4 the motion restricting means comprises an inverted J-slot cut in the wall of the second tubular member 35 and a pin 38 is fixedly attached to the first tubular member 32. In the embodiment of FIG. 5, the motion restricting means comprises hydraulic motion damper means as hereinafter described.

Referring now to the embodiment of FIGS. 1-4, it can be seen that in operation the pipe string 15 is run into the hole with the bumper sub expanded. The pin 38 is positioned at the bottom of the slot 37 so that the second tubular member 35 is in its uppermost position with respect to the collar 30. This allows fluid to bypass swab 20 by flowing through by-pass ports 34 and out the top 29 of annular space 33. When the fishing string is set down on the fish 14 the second tubular member 35 slips downwardly with respect to the collar 30 until the pin 38 reaches the top of the slot 37. At this point the sealing members 36 close the annular space 33 to fluid flow. A one quarter turn of the pipe string 15 to the left then locks the pin 38 in position at the top of the slot 37. Thereafter, as the drill string 15 is lifted, the sealing members 36 are retained in their sealing position so that fluid cannot by-pass the swab cups 22.

When it is desired to re-open the fluid pathway through by-pass ports 34, the drill string 15 is rotated a quarter turn to the right. This places the vertical portion of the slot 37 in alignment with the pin 38. The second tubular member 35 is then free to slide upwardly with respect to the first tubular member 32 until the pin 38 rests at the bottom of the slot 37. In this position the sealing members 36 are not in engagement with the collar 30.

In the embodiment of FIG. 5, the hydraulic motion damper means 47 can be any suitable hydraulic means for retarding the motion of two or more slideably connected members in response to a force tending to slide one of the members with respect to the other. Such hydraulic means generally comprise a system in which relative sliding movement of the members causes a viscous liquid to flow through one or more relatively small orifices. The force required to cause the liquid to flow through the orifice acts in opposition to the force causing relative sliding motion of the members and thereby retards this sliding motion. A suitable hydraulic motion damper means is a conventional hydraulic well jar of the type designed to expand in length slowly for a limited time when subjected to an axial tensile force and then to expand rapidly for a limited distance to impart an impact to a stuck pipe. A typical hydraulic well jar of this type is the "Bowen Hydraulic Rotary Jar" illustrated in the *Composite Catalogue of Oil Field Equipment and Services*, 27th Revision 1966-67, Volume 1, page 740.

The hydraulic damper means 47 of FIG. 5 comprises an annular chamber 48 enclosed by the internal wall of second tubular member 35, the external wall of first tubular member 32 and by upper and lower fluid-tight seal means 49 and 50. The seal means 49 and 50 are fixedly connected to first tubular member 32 and are in sliding sealing engagement with second tubular member 35. A flow restricting ring 51 having a plurality of orifices 52 is fixedly connected to the second tubular member 35. The ring 51 slidably engages the first tubular member 32 at a point intermediate the fluid tight seals 49 and 50.

In operation, a viscous liquid, e.g., an oil, is placed in the annular chamber 38. Axial sliding motion of the first and second tubular members 32 and 35 causes one of the fluid tight seal means 49 and 50, depending upon the direction of the axial motion, to act as a piston which drives oil in the chamber 48 through the orifices 52 in ring 51. This retards the rate of relative axial movement of the tubular members 32 and 35 to a speed proportional to the rate which oil in the chamber 48 flows through the orifices 52. The rate of axial movement of the tubular members 32 and 35 under a given axial force can thereby be adjusted by varying the diameter of the orifices 52, the viscosity of the oil in chamber 48, or both. A proper combination of these parameters is selected so that under a given tension expected to be exerted to free the fish 14, the rate of relative movement of the tubular members 32 and 35 will be such that in lifting the drill string 15, the rubber sealing members 36 will remain in contact with the interior wall of the collar 30 until the bumper sub 18 is fully expanded and will some time thereafter move out of sealing engagement with the walls of the collar 30 as the second tubular member 35 moves upwardly with respect to the first tubular member 32. This has the advantage of providing means for opening the annular space 33 to fluid flow while withdrawing the drill pipe 15 and attached apparatus from the borehole 10 without requiring interruption of the upward motion of the drill string 15 or manipulation of the drill string.

In the embodiment of both FIGS. 4 and 5, valve means 21 and 53, respectively, are positioned in the drill string 15 adjacent the jar 18 for closing the flow path drill string and jar 18 to fluid flow during the swabbing operation. This valve may be of any type suitable for use downhole to close the interior of a pipe string to fluid flow. It may be a valve activated by rotation of pipe string 15 such as a ball valve, or, for example, may be a valve activated by longitudinal movement of pipe string 15 such as a sleeve valve or the valve 21 and 53 of FIGS. 4 and 5.

Valve 21 (FIG. 4) comprises a valve seat 39 connected to the first tubular member 32. An annular piston 40 is carried by second tubular member 35. The piston 40 has a central bore 41 which terminates at its lower end in an upset portion 42 having a tapered edge 43 for sealingly engaging the seat 39. When the second tubular member 35 moves downwardly with respect to the central tubular member 32 as described above, the piston 40 is moved into sealing engagement with the seat 39. This prevents fluid from flowing down pipe string 15 into packed-off borehole portion 23. Stop means such as upset ridge 44 limits the downward movement of the piston 40 within the second tubular member 35. Bias means such as spring 45 is preferably provided to urge the piston 40 to its lowermost position to insure sealing engagement of the piston with seat 39. The seat 39 is held in place by a number of spaced connector members 46 which are fixedly attached to both the seat 39 and the central tubular member 32. When the valve 21 is open, fluid may flow down the tubular drill string 15 through the bore 41 of the piston 40 and then through the annular space surrounding the seat 39 adjacent connecting members 46.

The valve 21 of FIG. 4 has the advantage of being of the check type. It will automatically open under the influence of an upwardly directed pressure drop across piston 40 sufficient to exceed the biasing force of the

spring 45. This further assures that fluid will be able to flow past the fishing apparatus of FIG. 4 as this apparatus is lowered into the borehole 10. During the swabbing operation, decreased pressure below the valve 21 creates a downwardly directed pressure drop across piston 40 which works in combination with spring 45 to urge piston 40 into sealing engagement with seat 43.

Upward movement of second tubular portion 35 with respect to first tubular member 32 (as described above with reference to opening the fluid pathway through bypass ports 34) moves piston 40 away from seat 34. Drilling fluid can then be circulated down pipe string 15 through jar 18 and fish 14 as the fish is withdrawn from the borehole 10.

The valve 53 of FIG. 5 similarly is one which is opened and closed by relative axial motion of the first and second tubular means 32 and 35. There, flow is controlled by an annular sleeve 54 having a cylindrical central bore 55 attached to first pipe member 32 and a piston 56 attached to second pipe member 35 as by connecting rod 58 and support means 59. The piston sealing engages the central bore 55 of the sleeve 54 to prevent fluid flow through the bore 55 past the piston. A bypass channel 57 connects the bore 55 in communication with the interior of second pipe member 35 above the sleeve. The length of the connecting rod 58 is such that when the second pipe member 35 reaches its uppermost position with respect to first pipe member 32, the piston 56 is positioned above the intersection of bypass channel 54 with the central bore 55 of the sleeve 54. This allows fluid to be circulated through the sleeve 54.

I claim as my invention:

1. A method of freeing a segment of pipe stuck in a fluid-filled well borehole by pressure differential sticking comprising the steps of:

packing off a compressed-liquid filled portion of the borehole adjacent the stuck pipe;

expanding compressed-liquid in the packed-off portion of the borehole while maintaining the borehole above the packed-off portion substantially full of fluid across the entire width of the borehole, the expansion of the compressed liquid causing a reduction in pressure in the borehole adjacent the stuck pipe; and

exerting an upwardly directed force on the stuck pipe while maintaining the liquid in the packed-off portion of the borehole in the expanded condition.

2. The method of claim 1 wherein the step of packing off a liquid filled borehole portion comprises packing off a borehole portion of variable volume; and wherein the step of expanding liquid in the packed-off portion comprises increasing the volume of the packed-off portion while preventing movement of fluid into the packed-off portion from portions of the borehole above the packed-off portion.

3. The method of claim 2 wherein the step of packing off a borehole portion of variable volume comprises positioning a swab means in the borehole; and wherein the step of increasing the volume of the packed-off portion of the borehole comprises moving the swab means upwardly in the borehole.

4. The method of claim 1 wherein the step of expanding compressed liquid in the packed-off portion of the borehole comprises pumping fluid out of the packed-off portion while maintaining the volume of the packed-off portion substantially constant.

5. A method of recovering a well-drill-string having a portion thereof stuck in a fluid-filled borehole by pressure differential sticking comprising the steps of:

detaching the free portion of the drill-string above the stuck portion and removing it from the well borehole;

lowering a string of pipe capable of being attached to the upper end of the stuck portion of the drill-string into the borehole;

attaching the string of pipe to the stuck portion of the drill-string;

closing the interior of the string of pipe and the space between the exterior of the string of pipe and the walls of the borehole to fluid flow at a point in the borehole above the stuck drill-string to form a packed-off borehole portion adjacent the stuck drill-string, the packed-off portion having an upper boundary;

moving at least a portion of the upper boundary of the packed-off portion of the borehole upwardly to increase the volume of the packed-off portion while simultaneously preventing the flow of fluid into the packed-off portion from portions of the borehole above the packed-off portion; and thereafter

moving the pipe string upwardly to exert an upwardly directed force on the stuck drill-string portion.

6. The method of claim 5 wherein the step of moving the upper boundary of the packed-off portion of the borehole to increase the volume of the packed-off portion comprises moving the upper boundary a sufficient distance to increase the volume of the packed-off portion at least 1 percent.

7. The method of claim 5 including the steps of after freeing the stuck drill-string, opening the interior of the string of pipe and the space between the exterior of the string of pipe and the well borehole to fluid flow; and withdrawing the string of pipe from the well borehole.

8. Apparatus for freeing pipe stuck in a well borehole by pressure-differential sticking, comprising:

means for packing off a fluid filled borehole portion adjacent the stuck pipe;

means for increasing the volume of the packed-off borehole portion to a selected increased volume while preventing fluid flow into the packed-off borehole portion;

and means for exerting an upwardly directed force on the stuck pipe while the pipe is in the packed-off borehole portion of increased volume.

9. The apparatus of claim 8 wherein the means for increasing the volume of the packed-off portion comprises a connecting member having upper and lower portions telescopically connected for limited movement between a closed position and a fully expanded position; and wherein the pack-off means comprises swab means connected to the upper portion of the connecting member.

10. The apparatus of claim 9 wherein the connecting member is hollow; and

wherein the packed-off means further comprises a valve positioned to control flow through the hollow connecting member; and

means for opening and closing the valve.

11. The apparatus of claim 10 wherein the means for opening and closing the valve comprises first and second axially slideably connected tubular members operatively connected to the valve and to the means for ex-

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erting an upwardly directed force on the stuck pipe, the valve being opened by relative axial motion of the tubular members in response to an upwardly directed axial force.

12. The apparatus of claim 11 wherein the means for opening and closing the valve further comprises hydraulic motion damper means for retarding the relative axial motion of the slidably connected members in response to an axial force.

13. Apparatus for recovering a pipe segment stuck in a partially cased well borehole by differential sticking comprising:

means for engaging stuck pipe;

a pipe string;

a bumper sub connecting the pipe string to the means for engaging stuck pipe, said bumper sub including a top portion and a bottom portion telescopically connected for movement between a closed position and a fully expanded position, said bumper sub having an interior flow passage in fluid communication with the pipe string for carrying fluid through the telescoping connecting member;

pack-off means, including swab means connected to the top portion of the telescoping connecting member, for packing off and swabbing the cased borehole above the stuck pipe segment to reduce pressure in the borehole adjacent the stuck pipe as the top portion of the telescoping connecting member is moved upwardly in the borehole; and valve means positioned in the pipe string adjacent the

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telescoping connecting member for selectively opening and closing the interior of the pipe string to fluid flow.

14. the apparatus of claim 13 including bypass means for allowing fluid to bypass the swab means.

15. The apparatus of claim 13 wherein the valve means comprises first and second axially slideably connected tubular members operatively connected to the pipe string and the bumper sub, the interior of the pipe string being opened to flow by relative axial motion of the tubular members in response to upward motion of the pipe string.

16. The apparatus of claim 15 wherein the means for opening and closing the valve further comprises hydraulic motion damper means for retarding the relative axial motion of the slidably connected members in response to an axial force.

17. The apparatus of claim 16 wherein the hydraulic motion damper means comprises:

a chamber containing viscous fluid;

means for restricting the flow of viscous fluid from a first portion of the chamber to a second portion of the chamber;

and means connected to one of the tubular members for forcing viscous fluid to flow from the first chamber portion to the second chamber portion through the flow restricting means in response to relative axial movement of the tubular members.

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