Nov. 19, 1957 J. E. WALSTROM 2,813,585

BOTTOM-HOLE FORMATION TESTER

Filed March 1, 1954 2 Sheets-Sheet 1

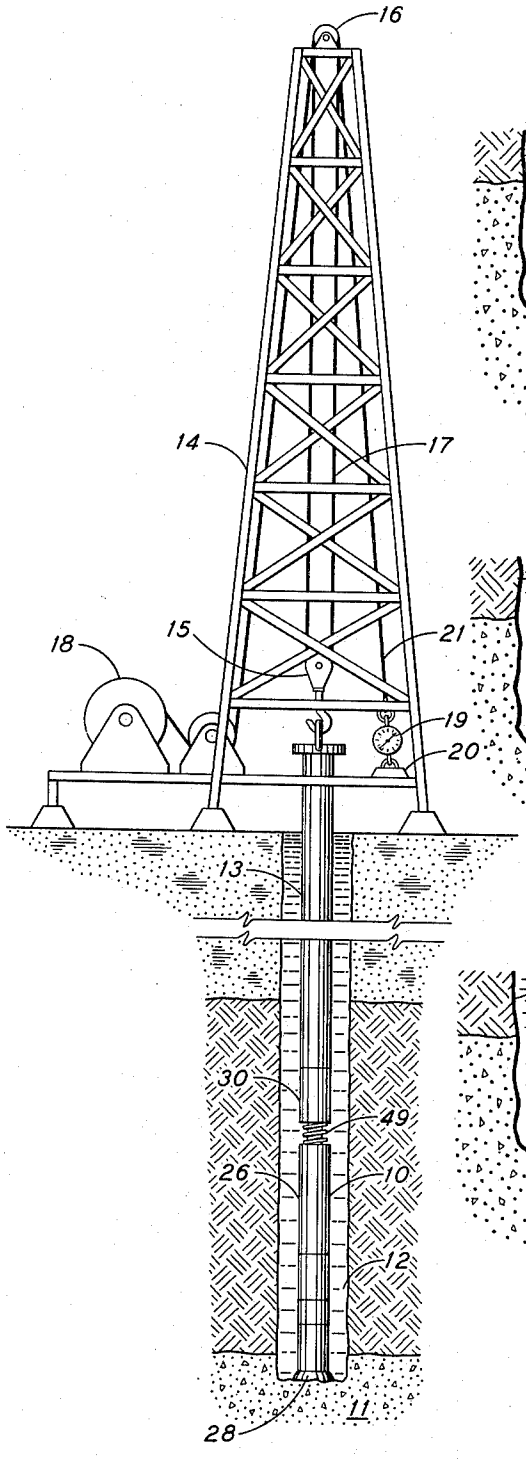


FIG. 1

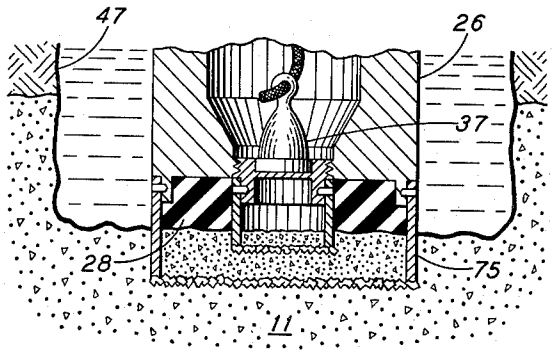


FIG. 4

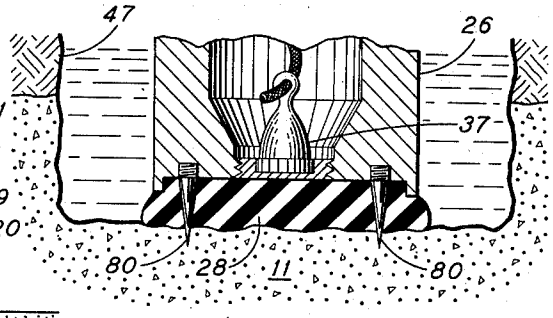


FIG. 5

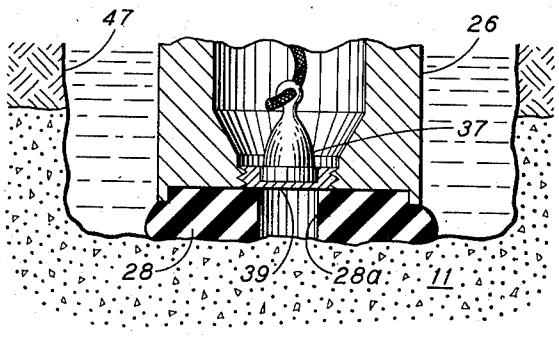


FIG. 6

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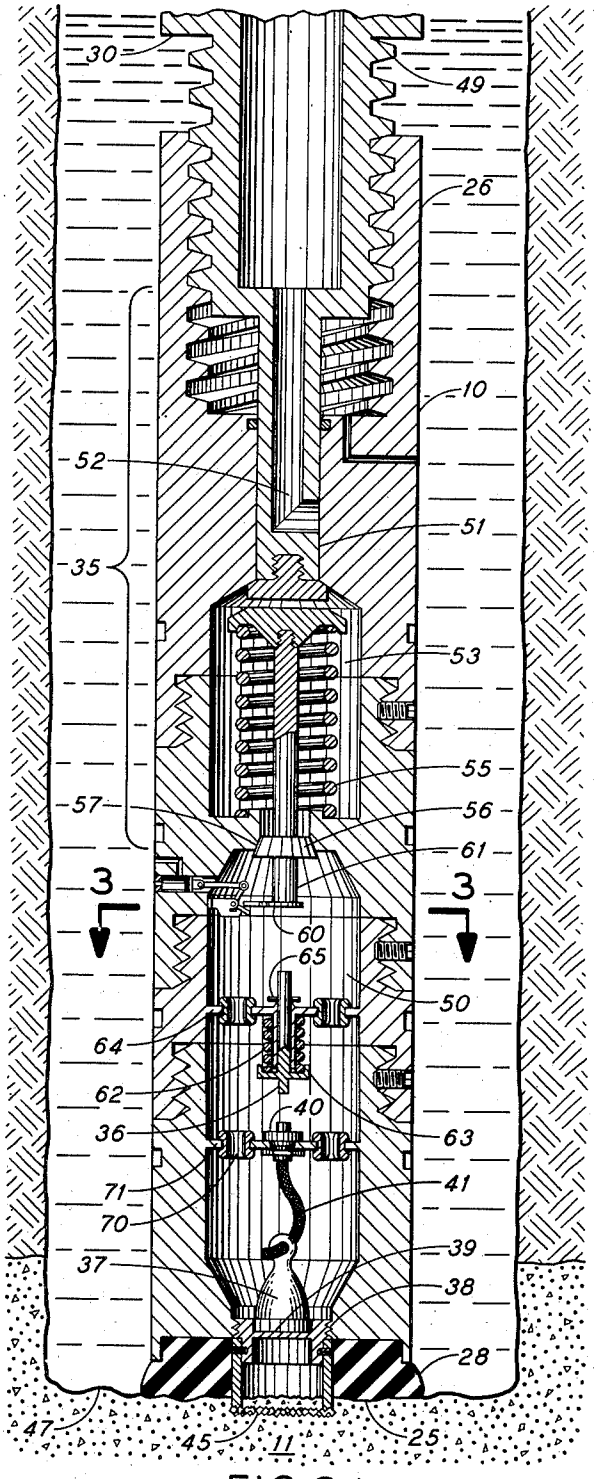


FIG. 2

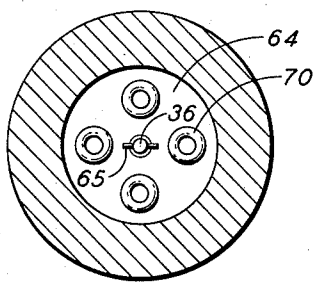


FIG. 3

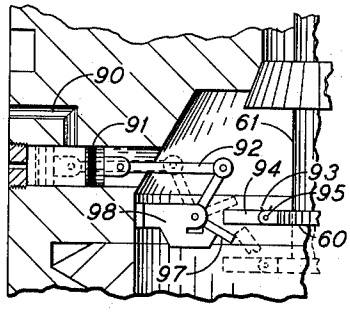


FIG. 7

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BOTTOM-HOLE FORMATION TESTER

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Application March 1, 1954, Serial No. 413,006

5 Claims. (Cl. 166—63)

The present invention relates to apparatus for withdrawing fluid samples from earth formations traversed by a bore hole, more particularly to apparatus for sampling fluid content of a formation through the bottom of a bore hole and has for an object the provision of an improved apparatus for open-hole sampling in situ of the fluids contained in earth formations lying at the bottom of the bore hole by reducing the hydrostatic head on a portion of said bottom while controlling the vertical thrust on the body member of the sampling device to maintain a tight fluid seal against the bottom of an open-full-sized bore hole both before and during withdrawal of the fluid sample, said vertical thrust being controlled by adjustment of the weight of the drill pipe supported on said body.

During the drilling of wells for oil, gas and the like, it is often desirable to test the fluid content of formations lying directly at the bottom of the bore hole. Such testing is often done upon obtaining an oil or gas show in the drilling fluid or cuttings that are continuously received at the surface of the well bore as a result of the circulation of the fluid stream. Heretofore, such bottom-hole drill stem testing of fluid content has only been accomplished by pulling the pipe and running a drill stem testing tool utilizing one or more full hole sidewall packers set near the bottom of the hole. In deep holes it is often not feasible to run full hole packers to the bottom of the hole due to the small clearance that exists between these packers and the sides of the hole and due to other operating difficulties. In such an instance it becomes necessary to pull the drill pipe out of the hole, put on a smaller size bit, drill ahead in small size hole, remove the drill pipe and run a drill stem tester equipped with one or more reduced-size sidewall packers to fit the reduced hole; or a cone packer to seat on the shoulder at the top of the reduced size hole. However, this latter type of formation fluid testing operation is extremely costly due to the necessity of stopping the normal drilling operation to drill a reduced diameter hole, and subsequently requiring opening of the hole to its full-hole size again. Additionally, boring ahead into the formation to establish the reduced-size hole may result in passage entirely through a potentially productive oil zone into a water zone, shale, or other uninteresting formation.

A principal advantage of the present invention, therefore, is that when full-hole packers cannot be run into the hole due to the great depth of the hole, irregularities prevailing in the hole, or other operating conditions, there is provided means for making a bottom hole test, without the necessity of drilling reduced hole, and the several attendant disadvantages of such an operation.

In accordance with the present invention, there is provided an apparatus for bottom-hole formation testing to determine the fluid content of earth formations lying directly ahead in a bore hole which may be used at any time during the drilling of a well without departure from conventional full-sized hole drilling procedures, and without requiring use of conventional sidewall packers and their restricted clearances. Further, the formation fluid content is sampled in adequate volume to obtain a true representation of the fluid in accordance with the invention by supporting the testing apparatus at the lower end of a string of conventional drill pipe. In carrying out the invention, a body member is provided with means for sealing the lower-end face portion of the body into engagement with the bottom of the bore hole while the vertical thrust on the body member against the bottom of the bore hole and the formation is controllably adjusted by regulating the weight of that portion of the drill pipe which is supported on the end face packer means. In a preferred form of the invention, bullet or shaped-charge means are provided for piercing the lower face portion of the body member in contact with the bottom of the hole to open port means in said sealing means and establish an elongated hole into the formation through which formation fluid may readily enter the testing tool and rise within the drill pipe. Further, in accordance with the invention, valve means are provided between the bottom of the drill pipe and the body member to provide a shut-off after fluid has accumulated in the drill pipe to prevent said fluids from being pushed upward and out of the drill stem as a result of the sudden entry of drilling fluid from the bore hole through the open port, upon unseating the testing tool from the bottom. Pressure-equalizing valve means, operable when said shut-off valve means are closed, are provided to equalize the pressure across the entrance port means and the bottom-hole packer means and permit ready removal of the tester apparatus.

Further objects and advantages of the present invention will become apparent from the following detailed description taken in conjunction with the accompanying drawings which form an integral part of the present specification.

In the drawings,

Fig. 1 is a diagrammatic representation of a preferred form of the present invention illustrating the manner in which the testing tool is supported in the well bore and controllably brought into sealed engagement with the bottom of the bore hole and the formation whose fluid content is to be tested.

Fig. 2 is an enlarged cross-sectional view of the lower end of the testing tool illustrated in Fig. 1.

Fig. 3 is a view of a portion of the testing tool showing the flow ports and firing pin in the direction of arrows 3—3 in Fig. 2.

Fig. 4 is an enlarged view of the lower end of the tool shown in Fig. 1, illustrating an alternative formation cutter and sealing arrangement for the lower end of the embodiment shown in Fig. 2.

Fig. 5 illustrates another modification of the lower end of the testing tool of Fig. 1.

Fig. 6 illustrates a further modification of the lower end of the formation sampling tool.

Fig. 7 is an enlarged view of the pressure-equalizing valve means, illustrating its operation after withdrawal of a sample from the formation under test.

With reference to the drawings, and in particular Fig. 1, there is illustrated a preferred form of apparatus for carrying out the present invention, in which a fluid sampling tool **10** for withdrawing a sample of the fluid content of a formation **11** lying directly below the bottom of bore hole **12** is adapted to be supported in the bore hole on a stand of dry drill pipe, indicated generally as **13**. Drill pipe **13**, whose end is closed by tool **10**, in turn, is supported by drilling derrick **14** including traveling block **15** and crown block **16** through cable **17**. As will be understood by those skilled in the art, drill pipe **13** is

raised and lowered in the bore hole by cable **17** operating through traveling block **15** and crown block **16** by reeling and unreeling of cable **17** on drum **18**. The weight of the drill pipe **13** is arranged to be measured by dead weight indicator **19**, which is interposed between the anchor means **20** and the dead wire line **21**, the latter forming an extension of the end of cable **17** passing downwardly from crown block **16**.

The drill pipe and main body portion **26** of testing tool **10**, in accordance with the concept of the present invention, are of substantially smaller diameter than bore hole **12**, in order to permit the drill string and tool to be run in and out of the bore hole without interference between the bore hole walls and the tool.

Further in accordance with the present invention, during withdrawal of fluid from formation **11**, directly ahead of bore hole **12**, and to permit such fluid to enter the bore hole, as well as during withdrawal of fluid, the weight indicating means **19** and the pipe supporting means, including derrick **14** and cable **17**, provides a means for controlling the total thrust of the end face, or formation-engaging portion, **25** of the body **26** of fluid sampling tool **10** against the bottom of the bore hole. This control permits a pressure differential to be established between the inlet port means formed in end face **25** and the exterior of tool **10**, as will be more fully described below.

As more fully illustrated in Figs. 2, 4, 5, and 6, the end face portion **25** engaging the bottom of bore hole **12** comprises a packer means **28** adapted to be deformed by the vertical thrust on body member **26** to seal the lower end of body member **26** against the bottom. As indicated, packer means **28** has an undeformed diameter that is substantially the same as body member **26**. The thickness or length of packer **28** is substantially less than its diameter so that engagement with the side walls of the full-sized bore hole is prevented when the packer is deformed on bottom. Packer means **28** also permits the lower portion **29** of body **26** to be held stationary while the upper portion **30** is rotated to open valve means **35** between body member **26** and pipe **13**. Rotation of pipe **13** likewise serves to explode a shaped-charge **37** to rupture or pierce the bottom of the well bore and formation **11**. In the preferred embodiment of the invention, shown in Fig. 2, a threaded plug **38** forms the inlet port means into the conduit formed by fluid-receiving lower chamber **50** and upper chamber **53**, in lower body member **26**. Threaded plug **38** also positions shaped-charge **37**, behind a hold-back plate **39**, to increase the piercing depth of charge **37** into formation **11**, when detonated by the impact of firing pin **36** on blasting cap **40** which, in turn, ignites explosive cord **41** thereby to detonate shaped-charge **37**. As particularly illustrated in Fig. 2, plug **38** is provided with an annular cutter **45** which extends through packer means **28** so that the cutter may be brought into firm contact with the bottom of the well bore. Cutter **45** likewise is arranged to pierce the mudcake **47**, which normally surrounds the periphery of bore hole **12** and which cooperates with packer **28** to seal against the hydrostatic head of the drilling mud. Rotation of body **26** and drill pipe **13**, in a normal, clockwise direction, as viewed from the top of the bore hole, causes cutter **45** to drill slightly into formation **11** and permits packer **28** to seat more firmly on bottom to bring shaped-charge **37** into more intimate contact with formation **11**.

After packer means **28** is securely seated on bottom, upper portion **30** of tool **10** is then rotated in a counterclockwise direction in order to screw threaded portion **49** of upper section **30** into the mating portion of lower section **26**, thereby to open valve means **35** and permit communication between chamber portion **50** of lower portion **26** and the interior of the drill pipe **13**. In the present embodiment, the screw threads on end section **49** of upper portion **30** are preferably left-handed, so that counterclockwise rotation of the drill string **13**, with lower portion **26** held stationary by the bottom of the bore hole and the load placed thereon, will cause valve **35** to open.

As indicated, the valve means **35** for opening chamber **50** to the interior of pipe **13** comprises an extension section **51** on upper portion **30** of tool **10**, which includes an L-shaped conduit **52**, which is brought into communication with an upper chamber **53**, by the continued rotation of upper portion **30**, against the compression of spring **55**. Chamber **53** is likewise opened to lower chamber **50** by the longitudinal movement of section **51** which causes the downward movement of valve stem **61** and valve **56** away from its seat **57** in section **26**.

As noted above, downward movement of upper portion **30** likewise serves to explode shaped-charge **37** by releasing firing pin **36**. Release of firing pin **36** is accomplished by lower end **60** of the valve stem **61**, which is independent of section **51**, but urged downwardly by that section until end **60** contacts the upper end of firing pin **36**. Firing pin **36** is normally held in a cocked position by compression spring **62**, held between a cap member **63** and a transverse wall member **64**. The firing pin is retained in this position by a shear pin **65**, which is arranged to be severed by a further longitudinal thrust which may be applied by end face **60** of valve stem **61**.

It will thus be seen from the foregoing description that rotation of the upper section **30** not only serves to operate the multiple valve arrangement, identified as **35**, but also at the end of its travel, serves to ignite the shaped-charge **37** to open a perforation into formation **11** lying directly ahead in the bore hole. In this way, the hydrostatic pressure on that formation may be reduced through the perforation and at the same time a flow path may be established into lower chamber **50** by rupture of disk **39**. The four wear rings **70** in lower plate **71** and similar wear rings in plate **64** permit fluid to rise through chamber **53** and into the interior of drill pipe **13** under the reduced pressure therein which will be substantially atmospheric. Upon completion of the bottom-hole formation test, valve means **35** may be closed by clockwise rotation of the upper portion **30** relative to lower portion **26**, while a predetermined weight is maintained on the bottom of the well bore, by controlling the weight of tool **10**, as indicated, at the top of the well by drill weight indicator **19**.

When valve means **35** is closed, a pressure equalizing valve arrangement, particularly illustrated in Fig. 7, is arranged to be opened by the retraction of valve stem **61** to its original position so that the inlet port means may again be at the same pressure as the drilling fluid. This feature is particularly desirable to prevent the difference in pressures, established during the formation test, from holding the tool on bottom. As shown, a lever arm **94**, pivoted on pin **95**, is normally held in a horizontal position by spring **93**, but during the opening of main valve means **35**, arm **94** is permitted to trip past lever **97** which is linked through bracket **98**, and connecting rod **92** to sliding valve **91**. Valve member **91** is held in the illustrated position by a stop on bracket **98** and the difference in fluid pressure between chamber **50** and the bore hole before and during the formation test. However, when main valve stem **61** is retracted to its original position, equalizing valve **91** is forced outwardly by the linkage including connecting rod **92** to the position illustrated in phantom, so that conduit **90** is placed in free communication with chamber **50** and the pressure equalized between the inside and outside of packer means **28**.

In this way, the fluid sample entrapped in the interior of the drill pipe may be readily withdrawn as the drill pipe is raised and disassembled at the top of the well. Accordingly, a full test of the fluid content of formation **11** may be made at any stage during the drilling operation, without the necessity for drilling a rat-hole, or the necessity of running special packer arrangements thereinto to obtain a satisfactory seal-off against the static head of drilling fluid.

Referring now to the packer arrangements illustrated in Figs. 4, 5, and 6, there are shown various modifications

of the bottom-hole engaging means, or packer means, 28 and the inlet port means formed therein, which may be used in various types of earth formations whose fluid content is to be sampled. In the arrangement of Fig. 4, it will be observed that there is provided an additional ring or annular cutter means 75 which is substantially the same diameter as the lower end of tool 10. This arrangement permits drilling into the bottom-hole formation for a distance sufficient to permit penetration of the zone invaded by the drilling fluid and lying directly behind the mud-cake 47. In some very porous formations, this arrangement is highly desirable, since the invading fluids from the drill hole may prevent the taking of an adequate sample, due to the hydrostatic head in the well bore holding back the formation fluid. Accordingly, the arrangement of Fig. 4 permits a better penetration into earth formation 11.

In the arrangement of Fig. 5, there is provided an alternative arrangement for preventing rotation of lower portion 26, when it is desired to counter-rotate upper section 30 to open valve 35 and fire charge 37. As illustrated, a plurality of spikes 80 may be forced downwardly into the formation.

As illustrated in Fig. 6, the lower end of testing tool 10 may be seated in some types of formations without the necessity of drilling an annular area, such as those formed with the equipment illustrated in Figs. 2 and 4. Under these circumstances, the packer means 28 is provided with a circular opening 28*a* which in part forms an inlet port means through which the shaped-charge 37 may be fired directly against earth formation 11. This arrangement of inlet port means may, of course, be varied in accordance with the formation under test, and as particularly illustrated in the arrangement of Fig. 5, may be formed by charge 37 perforating the packer means 28, which may be solid throughout the end face 25 of bore hole tool 10.

From the foregoing description, it will be seen that an apparatus has been provided for testing formations lying at the bottom of a bore hole wherein a packer means for sealing the lower end of the body member of the testing tool is held in firm engagement against the bottom by control of the vertical thrust on the body by regulation of the vertical load applied to the derrick draw works. The apparatus is further characterized by there being provided means for relieving the hydrostatic pressure on the formation, including perforating means positioned immediately behind the packer means, capable of opening an inlet conduit to the interior of the tester body. The testing apparatus further includes means for actuating, or energizing, the perforating means to pierce the bottom of the bore hole, as well as means for opening said body to admit fluid and for closing the lower end of said body member to entrap formation fluid within the body of the testing tool and the drill pipe upon which the body member is supported. Pressure equalizing valve means, operable when the main valve recloses, are provided to permit ready removal of the tool from the bore hole.

Various modifications and changes in the foregoing apparatus will occur to those skilled in the art from the foregoing detailed description. Among such modifications which may be made without departing from the scope of the invention, is the means for exploding the shaped-charge within the body of the tester tool. The foregoing description has particularly illustrated and described the use of shaped-charges, but it will be apparent that other types of piercing, or perforating apparatus, such as gun perforating means, may be employed, and that the detonation thereof may be accomplished by the application of concussion or electrical energy.

Other modifications and changes may be made without departing from the scope of the invention, and all such modifications falling within the terms of the appended claims are intended to be included therein.

I claim:

1. Bottom hole formation testing apparatus comprising a body member, a drill pipe, means supporting said member from the drill pipe for axial and rotational movement relative thereto in a full-sized bore hole, said body member including an end face, having a diameter substantially less than the diameter of the bore hole in which it is to be employed, a deformable packer means covering a substantial portion of said end face for sealing said body member into engagement with an earth formation at the bottom of said bore hole, said deformable packer means having a normal diameter substantially the same as the diameter of said body member and having a thickness substantially less than the diameter thereof to prevent engagement with the side walls of said full-sized bore hole when said packer means is deformed on bottom, means for seating said body member on the bottom of said bore hole including weight control means for applying a predeterminable vertical thrust on said body member to deform said packer means, a fluid-receiving chamber extending axially through said body member and communicating with the interior of the drill pipe, formation perforating means secured to and forming a portion of the end face of said body member, said perforating means closing off the lower end of said fluid-receiving chamber and forming a plug therein, said packer means being in direct contact with at least a portion of said perforating means, means for actuating said perforating means to successively shatter the plug to form an inlet port means in said end face of said body member and to pierce the bottom of said bore hole to permit flow of formation fluids into the interior of both said fluid-receiving chamber of said body member and said drill pipe, normally open valve means in the line of communication between said fluid-receiving chamber and said drill pipe and means operable by relative movement between said body and said drill pipe for closing said valve means to entrap formation fluid.

2. Bottom hole formation testing apparatus comprising a body member adapted to be supported by a drill pipe in a full-sized bore hole, said body member having a diameter substantially less than the diameter of the bore hole in which it is to be employed, deformable packer means for sealing the lower end of said body member into engagement with the bottom of said bore hole, said deformable packer means having a normal diameter substantially the same as said body member and having a thickness substantially less than the diameter thereof to prevent engagement with the side wall of said full-sized bore hole when said packer means is deformed on bottom, weight control means for applying a predeterminable vertical thrust on said drill pipe and said body member to deform said spacker means and sealingly engage said packer with the bottom of the bore hole, a fluid-receiving chamber extending axially through said body member and communicating with the interior of said drill pipe, explosive formation perforating means secured in the lower end of said fluid receiving chamber, said packer means being in direct contact with at least a part of said perforating means, vertically movable means within said body member for exploding said perforating means to successively open said fluid-receiving chamber to the bottom of the bore hole and to pierce the bottom of said bore hole to permit formation fluids to flow through said chamber to the interior of said drill pipe, normally open valve means in the line of communication between said fluid-receiving chamber and said drill pipe and means operable by relative movement between said body and said drill pipe for closing said valve means to entrap formation fluid within said body member and said drill pipe, and means associated with said valve means, operable in response to relative movement between the drill pipe and said body for actuating said vertically movable means.

3. Bottom hole formation testing apparatus comprising a body member adapted to be supported by a drill pipe in a full-sized bore hole, said body member having

a diameter substantially less than the diameter of the bore hole in which it is to be employed, deformable packer means for sealing the lower end of said body member into engagement with the bottom of said bore hole, said deformable packer means having a normal diameter substantially the same as said body member and having a thickness substantially less than the diameter thereof to prevent engagement with the side wall of said full-sized bore hole when said packer means is deformed on bottom, weight control means for applying a predeterminable vertical thrust on said drill pipe and said body member to deform said packer means and sealingly engage said packer with the bottom of the bore hole, a fluid-receiving chamber extending axially through said body member and communicating with the interior of said drill pipe, explosive formation perforating means secured in the lower end of said fluid-receiving chamber and forming a plug therein, said packer means being in direct contact with at least a part of said perforating means, means for energizing said perforating means to successively open said fluid-receiving chamber to the bottom of the bore hole and to pierce the bottom of said bore hole to permit formation fluids to flow through said fluid-receiving chamber to the interior of said drill pipe, normally-open valve means between said fluid-receiving chamber and said drill pipe, means operable by relative movement between said body member and said drill pipe for closing said normally-open valve means to entrap formation fluid within said drill pipe, an auxiliary conduit between said fluid-receiving chamber and the bore hole, and normally-closed valve means in said conduit, said normally-closed valve means being operable in response to closing of said normally-open valve means for opening said fluid-receiving chamber to fluid in the bore hole to equalize the pressure difference across said packer means.

4. Apparatus for testing the fluid content of an earth formation lying at the bottom of a full-sized bore hole comprising a body member adapted to be supported by a drill pipe in full-sized bore hole, said body member including the lower end face having a diameter to permit passage of said body to the bottom of said well bore without substantial interference with the side walls of said bore hole, a deformable packer means covering a substantial portion of said lower end face of said body member and adapted to be deformed to seal the end of said body member into engagement with the bottom of said bore hole without engaging the side walls of the well bore, said deformable packer means having a normal diameter substantially the same as the diameter of said body member and having a thickness substantially less than the diameter of said body member to prevent engagement with the side wall of said bore hole when said deformable packer means is seated on bottom, weight controlling means for applying a predeterminable vertical thrust to said drill pipe against the bottom of said bore hole to deform said packer means against the bottom and into sealing engagement therewith, a fluid-receiving chamber extending axially through said body member and communicating with said drill pipe, frangible plug means in the lower end face of said body member to close said chamber, perforating means for successively shattering said plug to form entrance port means into said chamber and piercing the bottom of said bore hole to permit a portion of said formation at the bottom of said bore hole to be relieved of the hydrostatic head exerted on said formation by drilling fluid in said bore hole, a stem section, having a conduit formed therein, vertically movable in said body member, said conduit in one position thereof being connected to said chamber to communicate with said drill pipe, and in another position thereof being adapted to prevent communication between said chamber and said drill pipe, said stem section being connected to said drill pipe, so that relative movement of the drill pipe with respect to the body will move said section to the aforesaid position of communication, vertically movable means for actuating said perforating means operable in response to a further movement of said stem section beyond its position of communication, a normally closed conduit formed in a side wall of said body member between said chamber and the exterior of said body, and normally closed valve means in said conduit for admitting fluid in said bore hole to said chamber operable in response to reverse movement of said stem section to the aforesaid other position to equalize the hydrostatic pressure inside and outside of said body member.

5. Bottom-hole formation testing apparatus comprising a body member adapted to be supported by a drill pipe in a full-sized bore hole, said body member having a diameter substantially less than the diameter of the bore hole in which it is to be employed, deformable packer means for sealing the lower end of said body member into engagement with the bottom of said bore hole, said deformable packer means having a normal diameter substantially the same as said body member and having a length substantially less than the diameter thereof to prevent engagement with the side wall of said full-sized bore hole when said packer means is deformed on bottom, weight control means for applying a predeterminable vertical thrust on said drill pipe and said body member to deform said packer means and sealingly engage said packer with the bottom of the bore hole, a fluid-receiving chamber extending axially through said body member, means providing communication between said chamber and the interior of the drill pipe, explosive formation perforating means secured to the lower end of said body member and forming a plug in the lower end of said fluid-receiving chamber, said packer means being in direct contact with at least a part of said perforating means, said communicating means including a vertically movable valve means in said body member intermediate said drill pipe and said perforating means, said valve means being operable by said drill pipe responsive to relative rotation between said body member and said drill pipe in one direction to open when said body member is sealed on bottom, firing pin means operable in response to said movement of said valve means beyond its open position for exploding said perforating means to successively shatter said plug to form port means into the interior of said fluid-receiving chamber and to pierce the bottom of the bore hole to permit flow of formation fluids through the pierced bottom of said bore hole into said chamber and said drill pipe, a pressure equalizing conduit between said fluid-receiving chamber and said bore hole, and normally-closed equalizing valve means in said conduit operable in response to reverse rotation between said drill pipe and said body member, and means operable in response to relative movement of said drill pipe and body member in an opposite direction to close said first valve means, for actuating said equalizing valve means to open the latter.

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