

United States Patent

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[56]

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[54] **METHOD AND APPARATUS FOR BALANCING
 SUBSEA INTERNAL AND EXTERNAL WELL
 PRESSURES**
 8 Claims, 7 Drawing Figs.

[52] U.S. Cl. 175/7,
 166/.5, 175/25, 175/40, 175/69

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 E21b 41/00

[50] Field of Search. 175/7, 8,
 57, 65, 69, 71, 5, 6, 24, 25, 40, 48; 166/.5

ABSTRACT: Method and apparatus for maintaining a pressure balance between internal and external subsea well pressures during underwater drilling, entry and reentry operations conducted from a floating vessel remote from the subsea well comprising injecting gas into the wellhead apparatus in amounts sufficient to cause the density of the well fluid or mud returns below the surface of the sea to approximate the density of sea water and controlling the injection of such gas and thus the internal well fluid pressures by sea water well pressure differential and control means associated with valve means located in gas injection and return lines at the subsea well apparatus.

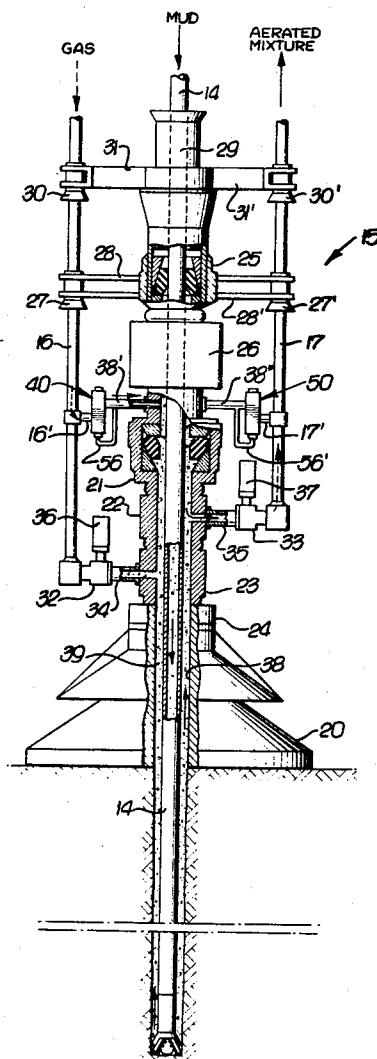


FIG. 2.

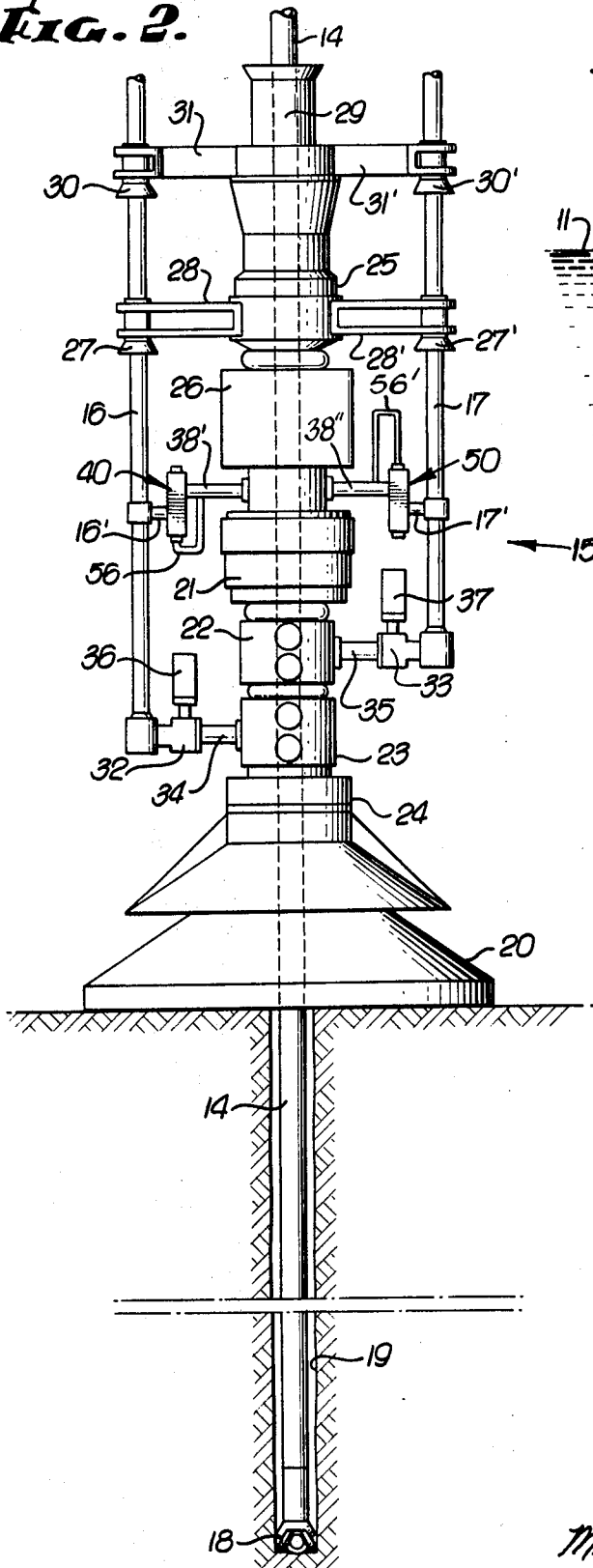
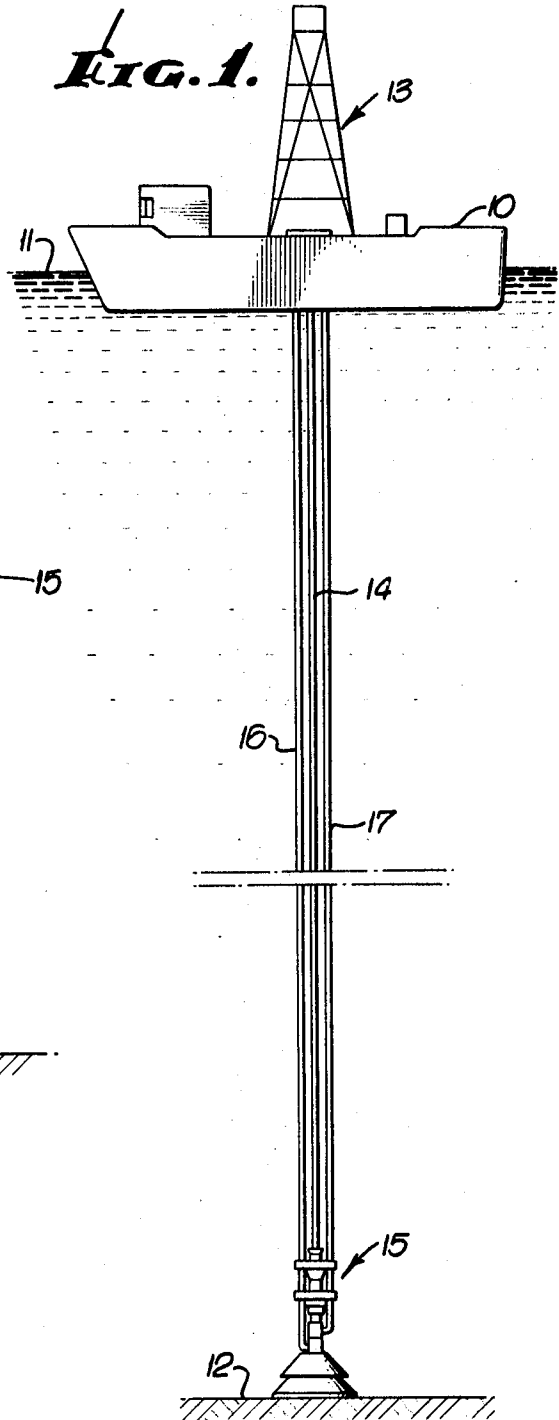


FIG. 1.



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FIG. 3.

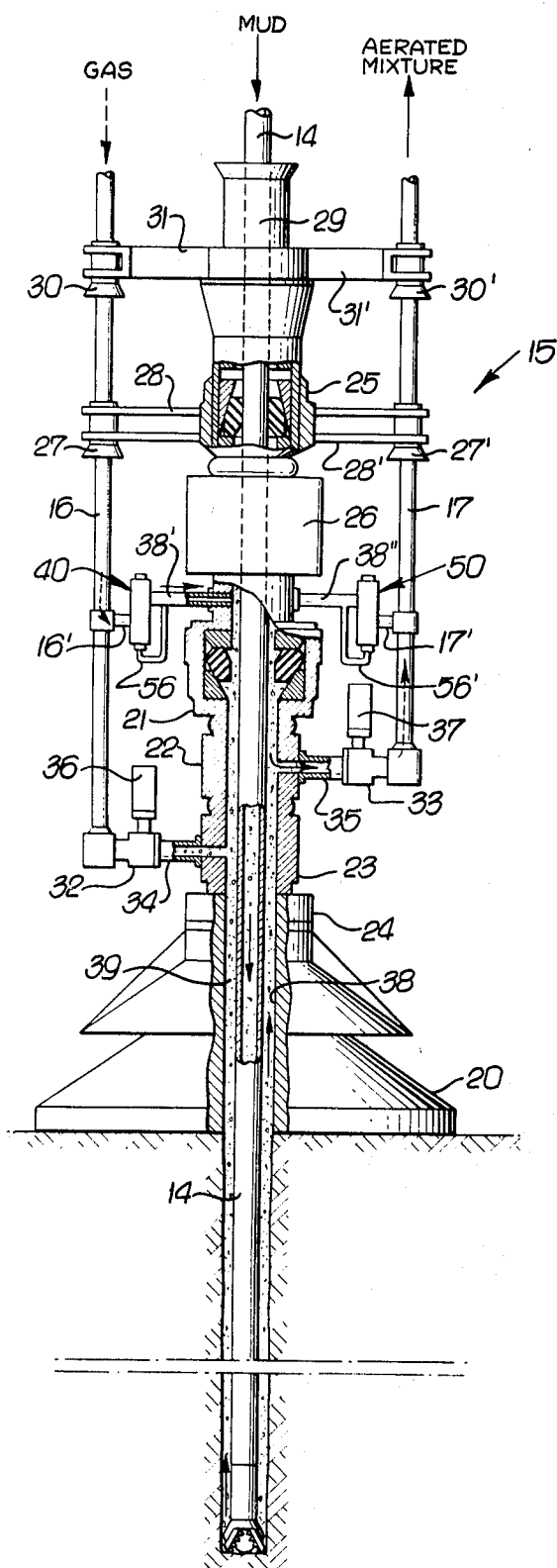
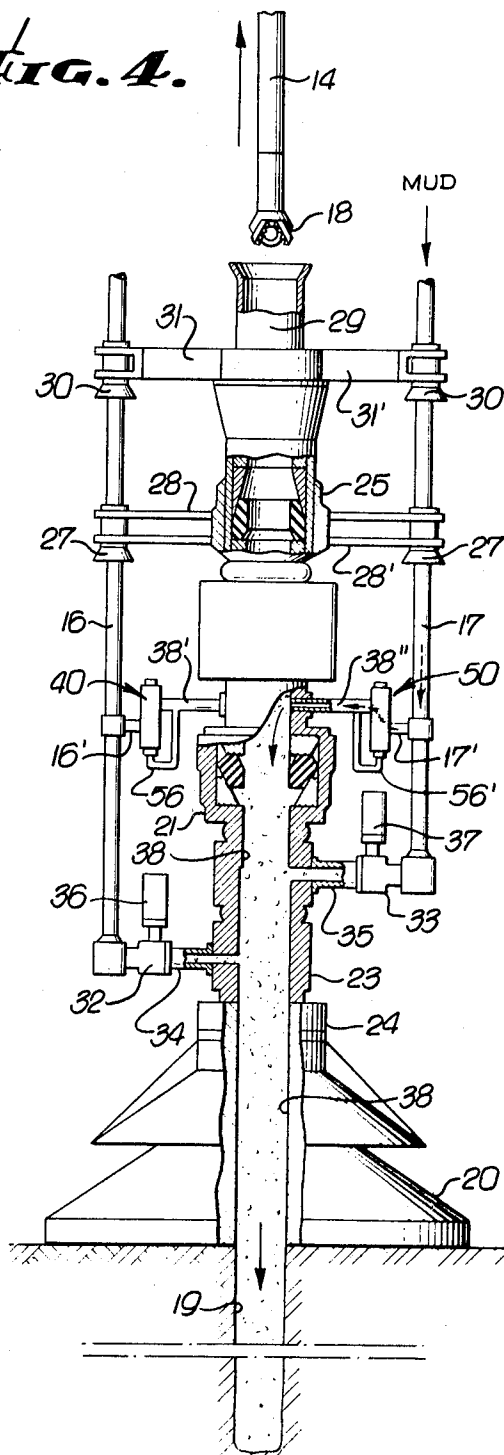


FIG. 4.



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FIG. 5.

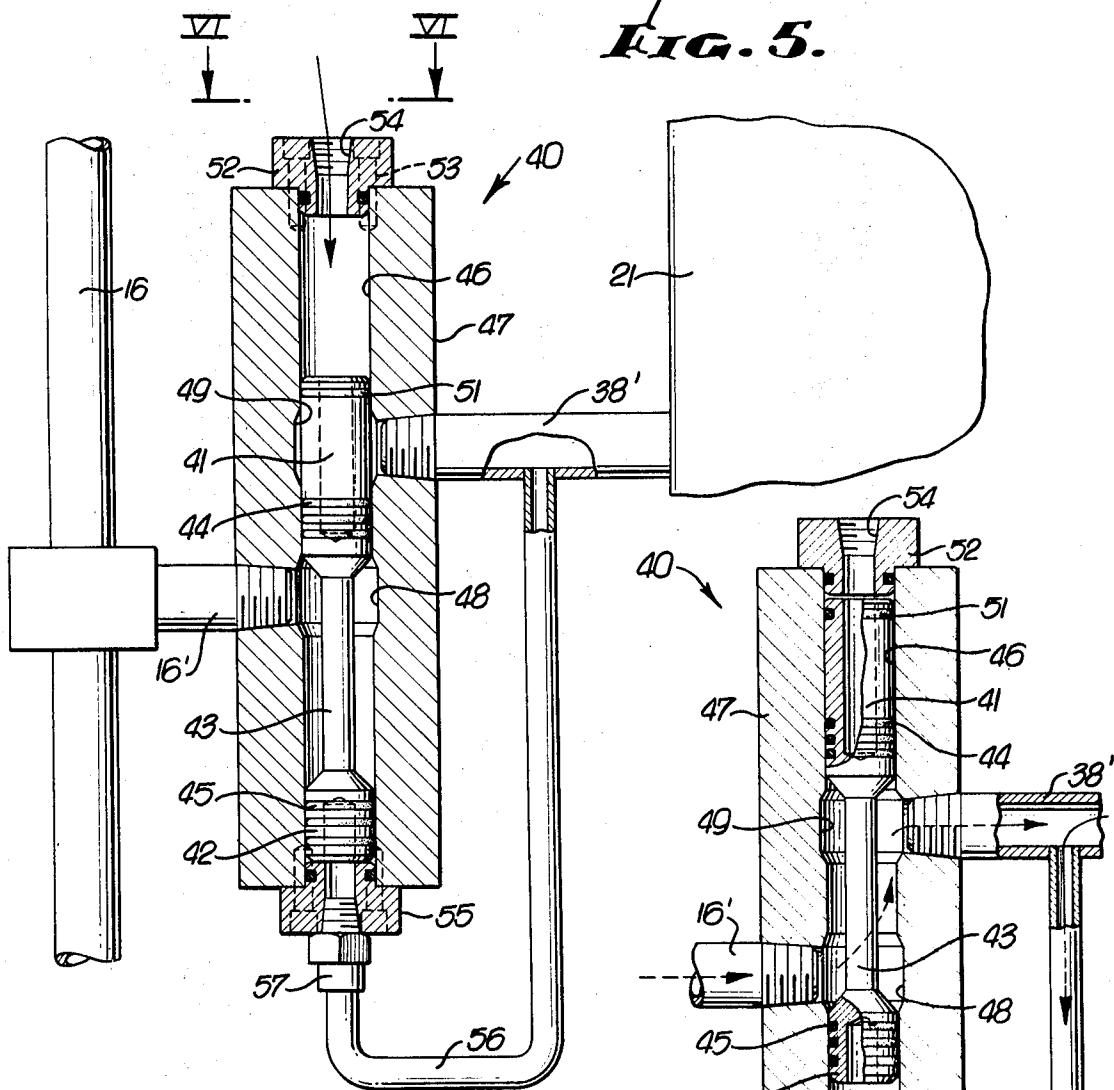


FIG. 7.

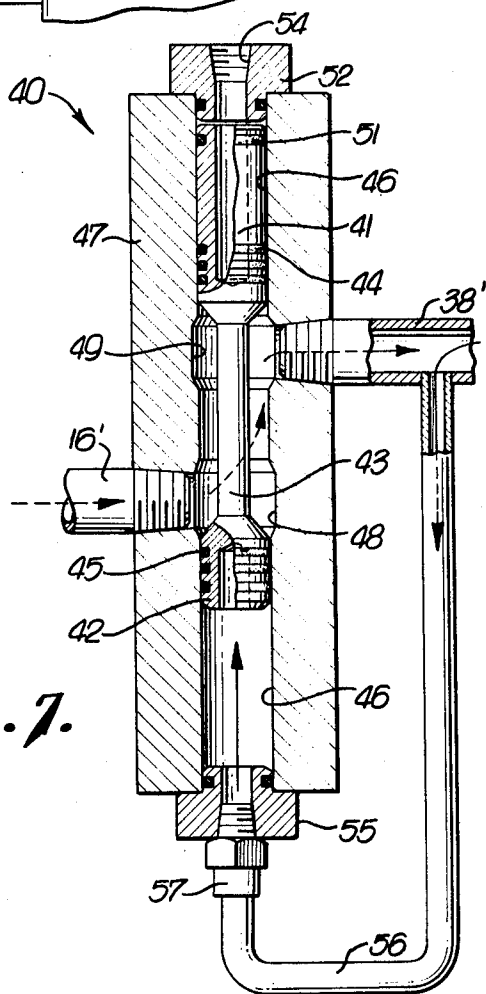
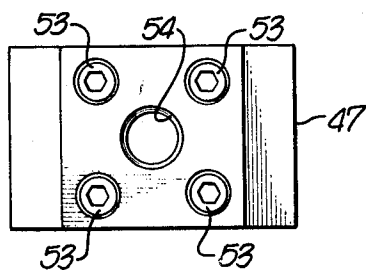


FIG. 6.



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METHOD AND APPARATUS FOR BALANCING SUBSEA INTERNAL AND EXTERNAL WELL PRESSURES

BACKGROUND OF THE INVENTION

Heretofore, most subsea well drilling operations have utilized a large diameter riser or conduit extending from a floating vessel's drilling rig down to the ocean floor where a well is to be drilled. The riser or large diameter conduit has been used to guide the drill string and associated drill bit into blowout preventers associated with the wellhead as well as to provide a return path for drilling fluids or "mud" being circulated between the floating vessel and the well during drilling operations. In subsea drilling, particularly in deep water locations, the use of such large diameter risers becomes impractical because of the high stresses imposed on the riser by surface and subsea water currents, weight of the drilling fluids or mud and uncontrolled movement of the floating vessel relative to the subsea well. In order to attempt to overcome these difficulties, it has been common heretofore to try to maintain the riser in tension between the vessel and subsea well by employing expansive cumbersome devices which have not proved entirely satisfactory.

In deep water subsea locations, it is desirable to eliminate the expensive and cumbersome devices referred to above. This has been accomplished heretofore by the use of only the drill string and small diameter circulating lines connected between the subsea equipment and the drilling rig. In this arrangement, a rotating blowout preventer is provided on the top of the blowout preventer stack provided at the wellhead. However, the substitution of a rotating blowout preventer at the top of the wellhead apparatus for the aforementioned riser creates at least two major problems. The well fluid or mud being more dense than sea water in the return lines creates a high back pressure inside the blowout preventer stack, such pressure frequently being twice the amount of pressure of the surrounding sea water. This means that such rotating blowout preventers in deep subsea well installations must operate continuously at very high pressure differentials between that of the internal well fluids and the surrounding sea water. Such pressure differentials increase the wear on the blowout preventer seals and the associated bearings. Also, there are elements in the drill string such as tool bits and stabilizers, as well as other tools, that cannot be easily stripped through the rotating blowout preventer when it is necessary to remove them from the well. It has not been possible heretofore to merely open the wellhead up and remove such tools without losing all of the drilling fluids or mud below sea level. It has heretofore been necessary to provide a plurality of blowout preventers spaced a sufficient distance apart so that odd shaped drilling tools can be pulled into a space between the blowout preventers with the upper one closed while the lower is opened. The lower blowout preventer or preventers are then closed and the upper one or more opened in order to allow removal of the tools. Such an arrangement requires an increase in the size and cost of the subsea equipment and also creates serious instrumentation problems, i.e. manipulating the various tools and controls for operating the blowout preventers from the remote floating vessel.

It is therefore the primary object of the present invention to solve the above problems by providing a method and apparatus for equalizing or closely balancing the drilling fluid pressure inside the wellhead with the surrounding sea water pressure so that the wear on the rotating blowout preventer is reduced and the underwater well can be opened for removal and reentry of tools without loss of drilling fluid.

It is a further object of the present invention to provide methods and apparatus for equalizing such well apparatus internal and external pressures by injecting a fluid of lower density than water, such as gas, into the well fluids at the wellhead apparatus prior to their return through the mud return lines to reduce the density of the drilling fluids to approximately that of the surrounding sea water.

It is a still further object of the present invention to disclose and provide methods and apparatus for balancing the internal and external pressures on a subsea wellhead apparatus as in the foregoing objects wherein further methods and means are provided for applying a back pressure on the well fluids in the wellhead apparatus to increase the internal wellhead pressures when they fall below a desired level.

SUMMARY OF THE INVENTION

Generally stated, the method of maintaining a pressure balance between internal and external subsea well pressures at a subsea well apparatus installation during drilling, entry and reentry operations conducted from a remote floating vessel of the present invention comprises injecting gas, such as air, into the subsea well in amounts sufficient to cause the density of the well fluids below the surface of the sea to approximate the density of sea water. More particularly, two or more fluid flow lines are established between the floating vessel and the bore of the subsea well apparatus with fluid returns from the well being returned through one of the lines. Gas is injected into the bore of the subsea well through the other of said lines in amounts sufficient to lower the density of the drilling fluids in the return line or lines thus exerting a pressure upon the internal bore of the well apparatus approximately equal to the pressure exerted thereon by the column of sea water above the apparatus. When such balance is achieved, the underwater well may be opened for the removal and reentry of tools without the loss of drilling muds or other well fluids.

The apparatus of the present invention, in general, includes one or more gas supply lines for injecting gas, such as air, into the subsea well apparatus bore for mixing therein with the drilling fluids or mud being returned to the surface by fluid return line or lines also provided. Valve means are provided in the gas supply line or lines at a location generally adjacent the subsea well for controlling the supply of gas to the well bore. As further contemplated within the present invention, sea water well pressure differential sensing means are provided in association with the valve means for operating such valve means in response to a pressure differential between that within the subsea well apparatus bore and that of the surrounding sea water. Also, it is contemplated that similar valve means and pressure differential sensing means may be utilized in association with the drilling fluid or mud return line or lines for applying a back pressure within the well apparatus bore through the return line or lines in the event internal well pressures fall below that of the surrounding sea water.

Further objects, various advantages and a better understanding of the apparatus and methods of the present invention will become apparent to those skilled in the art from a consideration of the following detailed explanation of an exemplary embodiment thereof. Reference will be made to the appended sheets of drawings in which:

IN THE DRAWINGS

FIG. 1 is a schematic representation, in elevation, of a floating vessel positioned above a subsea formation utilizing an exemplary embodiment of the balanced pressure drilling system in accordance with the present invention;

FIG. 2 is an enlarged elevational view of the subsea equipment of the apparatus of FIG. 1;

FIG. 3 is a somewhat schematic representation of the subsea equipment of FIG. 2, taken partially in section, illustrating the injection of gas into the well bore and drilling mud being returned up the mud return line;

FIG. 4 is another somewhat schematic view of the equipment of FIG. 2 showing the drill string removed, the well open to the surrounding sea water and illustrating how back pressure through the mud return line can be utilized in the balanced pressure drilling system of the exemplary embodiment of FIGS. 1 through 4.

FIG. 5 is a detail view of a portion of the equipment of FIGS. 1 through 4 partially in section, showing the associated valve apparatus in a closed position;

FIG. 6 is a plan view of a portion of the equipment of FIG. 5 taken therein along the plane VI—VI; and

FIG. 7 is another section view of the equipment of FIG. 5 showing the valve apparatus in an open position.

The method and apparatus for a balanced pressure drilling system will now be described in detail with reference to the aforescribed figures. Referring to FIG. 1 initially, a floating vessel or barge 10 is positioned by suitable anchoring means (not shown) in a body of water or sea 11 over a subsea well formation 12. A conventional drilling rig, indicated at 13, may be provided on the barge or vessel 10 for running a conventional drill string 14 down to the subsea equipment, indicated generally at 15, at the well site.

In accordance with the method and apparatus of the present invention one or more gas supply lines, as line 16, and one or more well fluid or drilling mud return lines, as return line 17, are connected in a manner hereafter described in greater detail between vessel 10 and the subsea equipment indicated generally at 15. A compressor, or other source, of gas or air on vessel 10 may be utilized for injecting or introducing gas into the well fluids or drilling mud being returned up line 17 in order to control the density thereof. Preferably, the gas or air introduced into the well fluids or drilling mud at the subsea equipment via supply line 16 reduces the density of the returns to that approximating the surrounding sea water. Thus, internal pressures within the subsea equipment due to the weight of the well fluid, or mud, returned in line 17 can be balanced against the external well pressures due to the presence of the surrounding sea water.

Referring now to FIG. 2, it can be seen that the drill string 14 is provided in conventional manner with a drill bit 18 at a lower end for drilling a well hole 19 through the well equipment indicated generally at 15. In the preferred exemplary embodiment, the well equipment indicated generally at 15 comprises a stack of blowout preventers and related equipment mounted upon drilling template 20 positioned over the location for drilling well hole 19. The stack of blowout preventers 21, 22 and 23 are mounted by a connector 24 upon template 20. A rotating blowout preventer 25 is mounted to the top of the aforementioned BOP stack by connector 26. Rotating BOP 25 is illustrated with conventional flanged guides 27, 27' mounted upon guide arms 28, 28' for running the rotating BOP to the subsea equipment via the preconnected lines 16 and 17.

The drill string may be run in conventional manner in cooperation with the bit guide 29, the latter having flanged guides 30, 30' mounted on the guide arms 31, 31', respectively. Choke and kill line-type valves 32 and 33 may be provided in the connections 34 and 35, respectively, between the subsea equipment inner bore and the lower ends of the flow line 16 and 17. Hydraulically or manually operated valve actuators 36 and 37 may also be provided in known manner. Valves 32 and 33 may be utilized for conventional choke and kill operations unrelated to the balanced pressure drilling method and apparatus of the present invention.

As particularly contemplated within the present invention, the internal and external subsea well pressures are balanced during drilling, entry and reentry operations conducted from the floating vessel 10. Such balancing of the internal and external well pressures is accomplished by introducing gas, such as air, into the subsea well bore via gas supply line 16 to control the density of the well fluid, such as drilling mud, returns back through return line 17. In accordance with the method and apparatus of the present invention, valve means are introduced into the gas supply line and are controlled by pressure differential sensing means which sense a pressure differential between the internal well bore pressure and the external, surrounding sea water pressure. In the preferred exemplary embodiment, such valve means and associated pressure differential sensing means are indicated generally at 40. Similar valve and sensing means, indicated generally at 50, as also contemplated within the present invention are provided between the well bore and return line 17.

Referring now to FIG. 3, the subsea equipment of FIG. 2 is illustrated partially in section to somewhat schematically show the introduction of gas, such as air, into the well fluids, such as drilling mud, being returned from the well bore up through the return line 17. During a conventional drilling operation, mud is introduced down through the drill string 14, through the drill bit 18 and then circulates back up through the annulus 38 formed between the well bore 19 and the exterior surface of drill string 14. Normally, such drilling fluids or mud have been returned up through the return line 17 to the vessel, with the weight of the dense drilling mud creating considering high pressures within the well bore below the rotating blowout preventer 25. The rotating blowout preventer is thus required to operate under conditions of continuous high differential pressure which is damaging to both the seals and bearings thereof. Further, there are frequently elements in the drill string, such as bits and stabilizers, that cannot be stripped through the rotating blowout preventer when it is necessary to remove them from the well.

In accordance with the present invention, these problems are solved by the equalization of the pressure inside the well-head with the surrounding water pressure by controlled introduction of gas or air into the mud returns via the valve and sensing means indicated generally at 40. As seen in FIG. 3, gas is injected down line 16, through valve and sensing means 40 into the well bore 38 where it comes into the well fluid returns 39. The gas injection into the fluid returns 39 lowers the density thereof and the mixture of gas and returns in line 17. By controlling the amount of gas injected through means 40, the density of returns in line 17 may be controlled to maintain the pressure differential across the rotating blowout preventer 25, and the differential between internal and external well pressures, at a minimum.

Referring to FIG. 5, the exemplary embodiment of valve means and differential pressure sensing means are illustrated generally at 40 connected between the gas supply lines 16 and the well apparatus (blowout preventer 21 in the exemplary embodiment). The valve means of the exemplary embodiment includes the valve body 41 slidably mounted within the valve housing 47. Piston member 42, connected to valve body 41 by stem portion 43, functions to stabilize the sliding movement of body 41 in bore 46 and as described subsequently, forms a part of the pressure sensing means. Bodies 41 and 42 are provided with fluid seals or O-ring seals 44 and 45, respectively, for sealing the bodies or members 41 and 42 within bore 46 of valve housing 47. Bore 46 is enlarged in bore area 48 adjacent the gas inlet conduit 16' and area 49 adjacent the outlet conduit 38' which is in fluid communication with the well apparatus bore 38.

Valve body or member 41 is shown in closed position in FIG. 5. Gas flow from line 16 into the well bore via line 38' is prevented due to the sealing engagement of seal means 44 and the surrounding housing bore 46. However, on an upward movement of valve member 41 into the open position of FIG. 7, gas flow from line 16', through housing bore 46 and line 38' to the well apparatus bore 38 is allowed. The opening and closing of valve member 41 relative to the lines 16' and 38' is controlled by associated pressure differential sensing means as hereinafter described.

Pressure differential sensing and valve actuating means are provided in association with the valve member 41 for operating such valve in response to a pressure differential between the surrounding sea water and the well apparatus bore pressure. In the exemplary embodiment, such pressure sensing means are provided by the upper and lower members 41 and 42 which act as piston members in housing bore 46. As seen in FIG. 5, valve member 41 is provided with a round pistonlike configuration with an upper end fluid seal 51. The upper end of housing 47 is open to the surrounding sea water pressure through the open end of bore 46. In the exemplary embodiment, an end fitting 52 is shown bolted by bolts 53 onto the upper end of housing 47 with a central threaded aperture or bore 54. While in the preferred exemplary embodiment, the

upper end of housing 47 is open to the surrounding sea water, it would be possible to apply a fluid line to aperture 54 for controlled application of pressure against the upper end of valve member 41.

The lower end of housing 47 is also provided with an end fitting 55 bolted to the housing. A conduit 56 is connected to the valve housing bore 46 via fitting 57, threaded into end fitting 55. The other end of conduit 56 is connected into the lines 38' on the well apparatus bore side of the valve housing. Well apparatus bore pressures in bore 38' on the well apparatus side of housing 47, are thus communicated via conduit 56 from line 38' to the bottom end of the second valve member or piston 42.

Referring to FIG. 7, when the well fluid pressures within well apparatus bore 38' exceed the surrounding sea water pressure, such pressure differential between the upper and lower ends of integral members 41, 42 and 43 causes an upward movement of such members from the position of FIG. 5 to that of FIG. 7. Gas is then injected through line 16', valve housing 47 and line 38' into the well apparatus bore until the variation of the well fluid reduces the well apparatus bore pressures to a value equal to or slightly less than the surrounding sea water pressures. When the sea water pressures exceed that of the internal apparatus pressures, valve and piston members 41 and 42 are moved back to the closed position of FIG. 5 stopping further injection of gas into the well fluid returns.

It is desired to maintain well bore pressures slightly above the value of the surrounding sea water pressures; the diameter of the lower piston 42 may be made somewhat smaller than that of the upper valve member or piston 41. However, in the preferred exemplary embodiment, the diameters of members 41 and 42, and their corresponding pressure surfaces exposed within bore 46 at the upper and lower ends of members 41 and 42 are equal to each other. With this arrangement, the associated valve means and pressure differential control means FIGS. 5 through 7 can be utilized to maintain the well apparatus internal bore pressures and surrounding sea water pressures very nearly balanced during the drilling operations.

In the event that the pressure within the well apparatus bore 38 falls below the surrounding sea water pressure, it is contemplated within the present invention that a valve means and associated pressure differential sensing and valve control apparatus, indicated generally at 50, constructed and operated as apparatus 40, may be utilized in association with the mud return line 17 as illustrated in FIG. 3. The internal construction and operation of the combination valve and pressure differential sensing and valve control means indicated generally at 50 is the same as that illustrated in FIGS. 5 and 7. However, the inlet conduit 17' to valve and pressure control means 50 is connected into the mud return line 17 while the outlet conduit 38'' is again connected into the well apparatus bore 38; as best seen in FIG. 4. In the event the pressure within bore 38 falls below that of the surrounding sea water pressure, the differential control means associated with means 50 senses the difference in pressure between the well fluids within the conduit 38'' and the surrounding sea water; opens the associated valve means and allows return of mud or drilling fluids back down line 17 into the well. The necessary back pressure in line 17 may be obtained by pumping drilling fluid back down line 17 in order to maintain the desired balance between internal and external well pressures.

By maintaining a very near balance between internal and external well bore pressures as aforesaid, the subsea apparatus may be opened up to the surrounding sea water as shown in FIG. 4, and the drill string 14 and associated tool, as bit 18, removed therefrom. As illustrated in FIG. 4, the blowout preventers are all in open position with the surrounding sea water pressure in balance with the internal well fluid to maintain control over the well even though it is open to the surrounding sea water. It can be seen from the foregoing disclosure that by using the pressure balancing apparatus and method of the present invention, the instrumentation required and the procedures for entry and reentry of subsea well ap-

paratus are greatly simplified. Drilling tools may be removed and inserted into the subsea well apparatus with the same ease and convenience in the subsea environment as though the well apparatus were on land. Having thus described an exemplary embodiment of the present invention, what I claim as my invention is set forth in the following claims.

I claim:

1. In a method of maintaining a pressure balance between internal and external subsea well pressures during drilling, entry and reentry operation conducted from a floating vessel remote from the subsea well including the step of injecting gas into the subsea well in amounts sufficient to cause the density of the well fluids below the surface of the sea to approximate the density of sea water, the improvement comprising the additional steps of:
 - sensing the pressure differential at said subsea well between internal well bore pressure and external water pressure and
 - controlling the amount of gas injected into said well bore to minimize the magnitude of said pressure differential being sensed.
2. In a method of maintaining a pressure balance between internal and external subsea well pressures during drilling, entry and reentry operations conducted from a floating vessel remote from the subsea well wherein drill mud is circulated from the vessel into the well during drilling operations and is returned to the vessel via a mud return line including the steps of establishing two or more fluid flow lines between the floating vessel and the bore of the subsea well, returning drill mud to the floating vessel from the well bore via one or more return lines of said fluid flow lines and injecting gas into the subsea well through one or more injection lines of said fluid flow lines in amounts sufficient to lower the density of said drill mud in said one or more return lines to approximate the density of sea water; the improvement comprising the additional step of:
 - applying a back pressure on said well bore by pumping drill mud down one or more of said lines to balance the internal and external well pressures when the internal well pressure falls below that of the surrounding sea water.
3. The method of claim 2 comprising the additional step of:
 - sensing the pressure differential at said subsea well between the pressure within said one or more return lines at said well and the surrounding water pressure, and
 - controlling the amount of drill mud introduced back into said well through said lines to minimize the magnitude of said pressure differential.
4. The method of claim 3 comprising the additional step of:
 - opening the well bore to the surrounding sea water to allow removal of and re-entry of well tools when the internal and external well pressures are in balance.
5. In a subsea well drilling apparatus including a drill string and drilling mud return line, each run from a floating vessel over a subsea well location to subsea drilling equipment at the well location, a blowout preventer means for sealing the well bore about the drill string within the well during drilling operations and gas supply line means run from said floating vessel and connected into said well bore below said blowout preventer means for injecting gas into the drilling mud to reduce its density as it is returned from said well to the floating vessel via said mud return line, the improvement comprising the provision of:
 - valve means in said gas supply line means at a location therein adjacent said subsea well for controlling the supply of gas to said well bore through said supply line means and
 - pressure differential sensing and valve control means in association with said valve means for operating said valve means in response to a pressure differential between the pressure in said gas supply line on the well bore side of said valve means and the pressure of the surrounding sea water.
6. In a subsea well drilling apparatus including a drill string and drilling mud return line, each run from a floating vessel

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over a subsea well location to subsea drilling equipment at the well location, a blowout preventer means for sealing the well bore about the drill string within the well during drilling operations and gas supply line means run from said floating vessel and connected into said well bore below said blowout preventer means for injecting gas into the drilling mud to reduce its density as it is returned from said well to the floating vessel via said mud return line, the improvement comprising the provision of:

valve means in said mud return line in a location therein adjacent said subsea well for controlling the back flow of mud from said return line back into said well bore; and pressure differential sensing and valve control means in association with said valve means for operating said valve

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means in response to a pressure differential between the pressure in said mud return line on the well bore side of said valve means and the surrounding sea water pressure.

7. The method of claim 1 comprising the additional steps of: opening said well bore to the surrounding sea water and running a well tool between said well bore and said floating vessel through said sea water and the opened well bore.

8. The method of claim 2 comprising the additional steps of: opening said well bore to the surrounding sea water and running a well tool between said well bore and said floating vessel through said sea water and the opened well bore.

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