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R. D. TOWNSEND, JR.
METHOD AND APPARATUS FOR LIGHTENING THE LOAD
ON A SUBSEA CONDUCTOR PIPE
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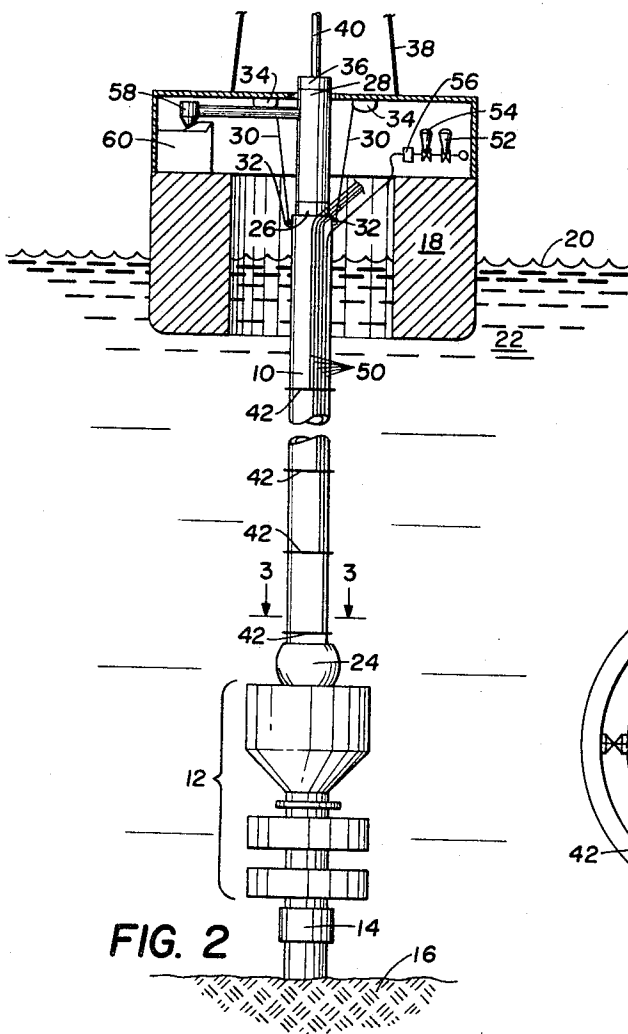


FIG. 2

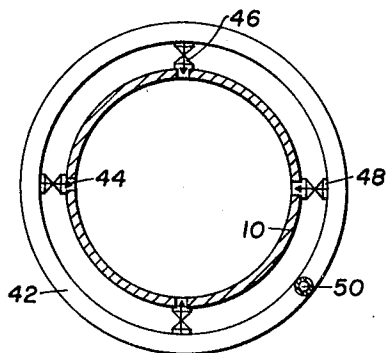


FIG. 3

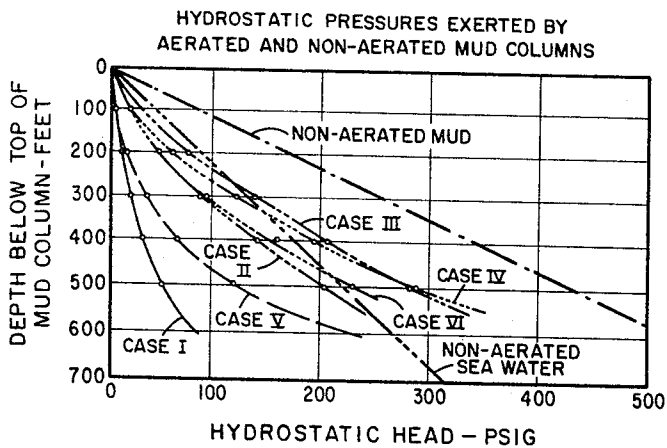


FIG. 1

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METHOD AND APPARATUS FOR LIGHTENING THE LOAD ON A SUBSEA CONDUCTOR PIPE

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8 Claims

ABSTRACT OF THE DISCLOSURE

This specification discloses a subsea conductor pipe communicating between a borehole in the formations underlying a marine bottom and a surface facility to provide a guide for a drill string suspended therein and for transporting drilling mud back to the surface facility from the borehole. Means are provided for injecting gas into the conductor pipe, at the lower end thereof, for lessening the weight of the contained drilling mud to lower the tensioning force necessary to prevent a structural or buckling failure of the conductor pipe. The gas utilized can be air, or when desirable, an inert gas. The gas can be injected only at the bottom of the conductor pipe or at spaced axial intervals to lighten the drilling mud in a program that would result in a hydrostatic head approximating that of the surrounding sea water.

This invention relates to a method and apparatus for the prevention of structural or buckling failures in marine risers or subsea conductor pipes, and more particularly to a method and apparatus for lightening the drilling muds therewithin, by injecting gas into the drilling returns, above the subaqueous borehole to lessen substantially the stresses or loads acting on the subsea conductor pipe.

To date, most successful offshore development drilling operations have utilized variations of the marine riser or conductor pipe system, in which a subsea conductor pipe is the basic means of communication between an above-surface drilling rig and the subaqueous well. A drill pipe is guided through the intervening body of water and into the well, and drilling mud is directed back to a surface facility through an annulus between the drill pipe and the conductor pipe. Any break or failure in the conductor pipe will at least result in a loss of drilling mud and expensive rig time.

To drill a well from a floating vessel using a subsea conductor pipe, the floating vessel is brought over the drilling location and securely anchored to the marine bottom or dynamically positioned with respect thereto. The conductor pipe is lowered through the water from the vessel and is fixed with respect to the marine bottom by any suitable means such as a surface casing hammered or jetted into the underlying formations, the subsea conductor pipe being coupled to the protruding end of the surface casing. The conductor pipe is relatively large diameter tube, relative to the diameter of the drill string and other necessary well tools, and it is of sufficient length to extend from the surface vessel to the surface casing at the marine bottom. The subsea conductor pipe is fitted with flexible and extensible joints in order to accommodate the unavoidable vertical and horizontal shifting of the floating surface vessel, relative to the formation, resulting from surface wind and wave actions.

A subsea conductor pipe designed for water depths of one hundred fifty feet or more is not usually a self-sustaining element and must be supported in tension with guy-lines from the vessel by a counterweighting system or constant tension winches, or by buoyant tanks mounted along the length of the pipe. In some cases the two methods are used in conjunction with each other. Due to

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the inability of a floating vessel to stay directly over the subaqueous borehole at all times and the tendency of the pipe to bow in the center from the force of ocean currents, the total amount of tensioning necessary in the pipe varies with the weight of the pipe, the weight of the drilling mud and the drill pipe string in the conductor pipe, and the allowable deflection in the pipe. As drilling progresses into deeper and deeper water the amount of necessary tensioning, to prevent a structural or buckling failure in the subsea conductor pipe, increases accordingly. To support completely such a system by counterweighting becomes unfeasible and therefore more and larger buoyancy tanks must be utilized.

Buoyancy tanks attached to the subsea conductor pipe have several drawbacks. One of these drawbacks is that a major horizontal force acting on the subsea conductor pipe, tending to bow the pipe and cause structural or buckling failures, is the prevailing ocean currents. It is therefore desirable to keep the outside diameter of the subsea conductor pipe as small as possible to reduce the area on which these currents may act and therefore reduce the magnitude of the forces involved. The addition of buoyancy tanks increases the diameter of the pipe and, therefore, the forces acting horizontally thereon. A danger related to the buoyancy tanks is that a failure of the conductor pipe in tension below the buoyancy tanks would result in the subsea pipe being driven up through the water and probably through the vessel, up above, resulting in not only irreparable damage in the pipe but the possible total destruction of the floating vessel as well.

As mentioned above, in considering the weight of the subsea conductor pipe for purposes of determining the necessary support from the vessel and additional buoyancy required, not only the weight of the pipe itself but that of the drill pipe string and the drilling mud within the conductor pipe must be taken into account. Since drilling mud may weigh as much as one hundred twenty-five pounds per cubic foot or more, this can be a considerable portion of the overall weight and a reduction in weight of the mud will reduce considerably the overall tensioning necessary to prevent structural or buckling failures in the pipe. A lengthy dissertation on the force involved in subsea conductor pipe failures due to buckling loads may be found in the recent article "Design of Floating Vessel Riser," by William Fischer and Milton Ludwig, in the Journal of Petroleum Technology, vol. XVIII, No. 3, March 1966, pp. 272-280.

Accordingly, it is an aspect of the present invention to lighten the drilling mud in a subsea conductor pipe, between the marine bottom and a surface vessel, to lower the over-all tensioning force necessary to prevent a structural or buckling failure of the conductor pipe.

It is another aspect of the invention to provide apparatus for injecting gas into a subsea conductor pipe to lighten the drilling mud returning from the borehole.

It is a further aspect of the invention to inject gas into a subsea conductor pipe in a program designed to minimize the tensioning forces necessary to prevent structural or buckling failures in the conductor pipe.

Other aspects and advantages of the invention will be readily apparent from the following description, when taken in conjunction with the accompanying drawings that illustrate useful embodiments in accordance with this invention:

FIGURE 1 is a composite graph illustrating the hydrostatic head exerted by sea water, a nonaerated mud column, and mud columns aerated according to different programs;

FIGURE 2 is a schematic representation of the marine riser or subsea conductor pipe, of the present invention,

providing communication between a floating vessel and a sub-aqueous borehole; and

FIGURE 3 is a cross-sectional view of the marine riser or subsea conductor pipe taken on line 3—3 of FIGURE 2.

The vertical loads imposed on the conductor pipe by the mud therewithin (when the pipe is not perfectly vertical) can be approximated as being the total weight of the mud in the conductor discounted for the buoyancy exerted by the sea water over that section of the conductor pipe below the water line. Stated in another way, the vertical load on the subsea conductor pipe at any point due to the weight of the mud column within the conductor pipe is equal to the hydrostatic head of the mud column at that point less the hydrostatic head of the surrounding sea water at that point, all multiplied by the net cross-sectional area within the subsea conductor pipe. Thus, any means of reducing the hydrostatic head of the mud column within the conductor pipe will reduce the vertical load on the pipe due to the mud, thereby reducing the structural or buckling loads on the pipe. Presumably, if the hydrostatic head of the mud within the subsea conductor pipe is reduced to less than the hydrostatic head exerted by the sea water outside the conductor pipe, the sea water would tend to support the pipe over the length on which it acted, with the buckling tendencies of the mud within the pipe reduced to less than zero over the interval below the water surface.

The principles and practice of injecting compressed air or gas into a mud column to reduce the hydrostatic head exerted by it on formations deep within a well have been recognized and followed for the past few years in drilling in areas where lost circulation is a problem when using normal mud circulation methods. The aeration of drilling mud within the annulus in the borehole has been used as an effective safety procedure, the mud being lightened with gas for drilling, and being additionally weighted by the cessation of the injection procedure when there is an indication of a blowout. It might appear at first glance that aeration of the mud column in the marine conductor could reduce to hazardously low levels the hydrostatic head exerted by the mud column in the borehole on potential high pressure formations, possibly permitting them to blow out. This need not be the case, however. A little thought will indicate that a very minor increase in the weight of the nonaerated mud circulated down the drill pipe into the borehole will, for all practical cases, insure that an adequate net hydrostatic head can always be imposed on any potential high pressure formation, no matter to what degree the rising mud column in the conductor pipe is lightened by aeration.

The graph of FIGURE 1 shows, for water depths up to approximately five hundred feet, the hydrostatic head exerted by sea water, nonaerated drilling mud weighing one hundred twenty-five pounds per cubic foot, and the same mud when injected with air according to different programs. The volume of air required to be injected will vary, obviously, with the weight of the mud, the reduction in hydrostatic head desired, and the rate of mud circulation. Cases I—VI show the variations of hydrostatic head of aerated mud columns at rest with depth for various degrees of aeration, as follows: (In all cases, nonaerated mud weight is one hundred twenty-five pounds per cubic foot.)

Case I.—15 cu. ft. of air per cu. ft. of mud injected at depth of 500 ft.

Case II.—5 cu. ft. of air per cu. ft. of mud injected at depth of 500 ft.

Case III.—3 cu. ft. of air per cu. ft. of mud injected at depth of 500 ft.

Case IV.—1 cu. ft. of air per cu. ft. of mud injected at each five points, at depths of 100 ft., 200 ft., 300 ft., 400 ft., and 500 ft., respectively.

Case V.—3 cu. ft. of air per cu. ft. of mud injected at

each of five points at depths of 100 ft., 200 ft., 300 ft., 400 ft., and 500 ft., respectively.

Case VI.—2 cu. ft. of air per cu. ft. of mud injected at 500 ft. plus 3 cu. ft. of air per cu. ft. of mud injected at 300 ft.

The hydrostatic heads exerted by flowing aerated mud columns would be slightly higher than those shown, because the friction loss in the conductor pipe would increase the flowing back pressure on the mud at any point in the conductor pipe, thereby reducing the air volume at that point and increasing the density, and therefore the hydrostatic head exerted by the aerated mud column at that point. However, the increase in hydrostatic head exerted by the moving aerated column over the same aerated column at rest is a matter of only a few percent. Inasmuch as it is only a matter of injecting slightly more air to reduce the hydrostatic head exerted by the moving column to the desired level, there is no great problem presented, once the curves are calculated.

From the curves, it is apparent that the hydrostatic head exerted by the aerated mud column can be varied at will by the point of injection and the quantity injected. Thus, the shape of the hydrostatic head versus depth curve for the aerated mud column can be varied to approximate any given curve as desired, such as, possibly, the straight line hydrostatic head versus depth relationship for sea water. Based on the various curves, it appears that the total volume of air to be injected, if the hydrostatic head of the mud column is to be brought approximately equal to that of the sea water surrounding the conductor pipe, will be of the order of five cubic feet of free air injected per minute per cubic foot of mud circulated per minute.

In addition to reducing the hydrostatic head, and therefore the buckling load, imposed by the mud column on the conductor pipe, the injection of compressed air or other gas in the rising mud column in the conductor pipe provides additional benefits. A first additional benefit is the reduction of the hoop or bursting loads acting radially outward on the wall of the subsea conductor. The lower the hydrostatic head of the returning drilling mud, the lower the hoop loads. Supporting the pipe from the vessel above or attaching buoyant tanks to the conductor pipe would not affect the hoop loads at all. A second additional benefit results when drilling or equipment procedures require the use of a large diameter conductor. In such a situation, the annular area between the drill pipe and conductor may be so large that the rising velocity of the nonaerated mud column in the annulus will be too low to insure complete lifting of the cuttings from the wellbore. A necessary concomitant of the reduction of hydrostatic head achieved by aerating the mud column in the conductor is that the specific volume of the air-mud mixture increases. Thus, for the same basic circulation rate for the mud, and for a constant bore diameter of the subsea conductor pipe, the specific volume of the air-mud mixture, and therefore its rising velocity, will increase as the mud column flows upward, and the air expands as the hydrostatic head exerted on it is reduced. Stated another way, the bore diameter, and therefore cross-sectional area of the conductor can be increased from sea bottom to sea level and above, and still maintain an adequate rising velocity of the mud column, if it is aerated.

In the foregoing, it has been assumed that the gas injected to lighten the rising mud column within the subsea conductor would be compressed air. If an oil-base drilling fluid is being used, or if the drilling mud is picking up oil or gas from the formation being drilled, it may be objectionable to inject compressed air into the thusly gas or oil cut mud, because of the hazards of explosion or fire. Under these circumstances, the injected gas could be an inert gas which will not support combustion. Diesel or gas engine exhaust gases, suitably cleaned and inhibited, are suggested as a logical choice

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for such a substitute gas, because there will almost certainly be an abundant supply of these available from the engines powering the rig and equipment on the drilling vessel. The only problems associated with their use will be the probable need to increase the amounts injected to make up for the solution in the mud stream of the carbon dioxide in the exhaust gases, and the additional problems in controlling the mud properties due to such solution. Neither problem appears to be significant enough to cause any great concern.

Now looking to FIGURE 2, in the implementation of this invention, a marine riser or subsea conductor pipe 10 is connected between subsea apparatus 12 consisting of blowout preventers and a wellhead, mounted atop a surface casing 14 protruding from the marine bottom 16, and a vessel 18 floating at the surface 20 of a body of water 22. A universal joint 24 is inserted between the conductor pipe 10 and the subsea blowout preventers and wellhead 12 to permit compensation for the unavoidable lateral movement of the floating vessel 18. A slip joint 26 in the conductor pipe 10 compensates for the vertical movement of the vessel 18 with the upper section 28 of the conductor pipe, above the slip joint, supported at or about the deck of the vessel 18. Guylines 30 are connected between the conductor pipe 10, at radially spaced points 32 below the slip joint 26 and constant tension winches 34 on the vessel 18, to provide support for the pipe 10. In place of the constant tension winches 34, the guylines 30 may be entrained over pulleys (not shown), the free ends thereof hanging in the water with counterweights attached thereto. Although at least one buoyancy tank would also help to tension the pipe, no such tank is shown here to permit the apparatus of the invention to be more clearly illustrated. A stuffing box 36 is fixed on the upper end of the conductor pipe section 28, and a drill pipe string 40 suspended from the rig 38 depends through the stuffing box 36 and the subsea conductor pipe 10 into the subaqueous borehole beneath.

A circular manifold 42 (FIGURES 2 and 3), around the conductor pipe 10, is installed at each level where compressed gas is to be injected into the rising mud column within the conductor pipe 10. Each of the manifolds 42 distributes the gas through a plurality of nozzles or ports 44 uniformly spaced around the circumference of the conductor pipe 10, through the wall thereof. A one-way or check valve 46 in each of the feed lines 48 from the manifold 42 to a nozzle or port 44 prevents the backflow of mud from the conductor pipe 10 into the manifold 42 if the pressure were bled off for any reason. For each manifold 42, a separate gas supply line 50 is run to the vessel 18, at the upper end of the conductor pipe 10, with the supply lines 50 clamped to the conductor pipe 10 at intervals. On the vessel 18, individual flow and pressure controllers 52 and 54, respectively, and recording gas meters 56 (only one control circuit shown) would control and meter the flow of the compressed gas to each manifold 42 as desired by the operator. In a particular instance the operator may not feel that a pressure control is necessary for the injection of gas. In this case the pressure controllers 54 can be omitted. The aerated drilling returns would be processed through a cyclone separator 58 to remove the included gas prior to being fed back to mud tanks 60 aboard the vessel 18.

Although the present invention has been described in connection with details of a specific embodiment thereof, it is to be understood that such details are not intended to limit the scope of the invention. The terms and expressions employed are used in a descriptive and not a limiting sense and there is no intention of excluding such equivalents, in the invention described, as fall within the scope of the claims. Now having described the method and apparatus herein disclosed, reference should be had to the claims which follow.

What is claimed is:

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1. In the drilling of subaqueous wells in formations underlying a body of water from a facility on the surface of a body of water; means for providing communication between said surface facility and a borehole in formations underlying the marine bottom to guide a drill pipe string into said borehole and constraining drilling mud returning to said surface facility, said communicating means comprising: a conductor pipe extending between said surface facility and a means permanently connected to said borehole for operatively connecting said conductor pipe into said borehole, and means for injecting gas into said returning drilling mud to lighten said returning drilling mud at one level at least within said conductor pipe, said means for injecting gas into the returning drilling mud comprises at least one manifold encircling said conductor pipe, and means for injecting gas from said manifold into said conductor pipe at radially spaced points around said conductor pipe whereby the weight of said mud within said conductor pipe is lessened to reduce the tensioning force required to support said conductor pipe in a body of water to prevent structural or buckling failures in said pipe and whereby the hydrostatic force of mud circulating within said borehole is substantially unaffected.

2. In the drilling of subaqueous wells in formations underlying a body of water from a facility on the surface of a body of water; means for providing communication between said surface facility and a borehole in formations underlying the marine bottom to guide a drill pipe string into said borehole and constraining drilling mud returning to said surface facility, said communicating means comprising: a conductor pipe extending between said surface facility and a means permanently connected to said borehole for operatively connecting said conductor pipe into said borehole, and means for injecting gas into said returning drilling mud to lighten said returning drilling mud within said conductor pipe including a plurality of port means for injecting gas into said returning drilling mud, said port means being at axially spaced levels along said conductor pipe; and means for regulating the flow of said gas being injected at said axially spaced levels, said flow regulating means being arranged to meter separately the gas injected into said returning drilling mud at said spaced levels to lighten said drilling mud according to a program to reduce the hydrostatic head of said returning mud column to approximate the hydrostatic head of the sea water surrounding said conductor pipe along the axial length of said conductor pipe whereby the weight of said mud within said conductor pipe is lessened to reduce the tensioning force required to support said conductor pipe in a body of water to prevent structural or buckling failures in said pipe and whereby the hydrostatic force of mud circulating within said borehole is substantially unaffected.

3. In the drilling of subaqueous wells in formations underlying a body of water from a facility on the surface of a body of water; means for providing communication between said surface facility and a borehole in formations underlying the marine bottom to guide a drill pipe string into said borehole and constraining drilling mud returning to said surface facility, said communicating means comprising: a conductor pipe extending between said surface facility and a means permanently connected to said borehole for operatively connecting said conductor pipe into said borehole, and means for injecting gas into said returning drilling mud to lighten said returning drilling mud within said conductor pipe including a plurality of ports means for injecting gas into said returning drilling mud, said port means being at axially spaced levels along said conductor pipe; and means for regulating the flow of said gas being injected at said axially spaced levels, said flow regulating means being arranged to meter separately the gas injected into said returning drilling mud at said spaced levels to lighten said drilling mud according to a program that results in

a hydrostatic head versus depth curve which is lower than the curve for sea water whereby the weight of said mud within said conductor pipe is lessened to reduce the tensioning force required to support said conductor pipe in a body of water to prevent structural or buckling failures in said pipe and whereby the hydrostatic force of mud circulating within said borehole is substantially unaffected.

4. In the drilling of subaqueous wells in formations underlying a body of water from a facility on the surface of a body of water; means for providing communication between said surface facility and a borehole in formations underlying the marine bottom to guide a drill pipe string into said borehole and constraining drilling mud returning to said surface facility, said communicating means comprising: a conductor pipe extending between said surface facility and a means permanently connected to said borehole for operatively connecting said conductor pipe into said borehole, and means for injecting gas into said returning drilling mud to lighten said returning drilling mud within said conductor pipe including a plurality of port means for injecting gas into said returning drilling mud, said port means being at axially spaced levels along said conductor pipe; and means for regulating the flow of said gas being injected at said axially spaced levels, said flow regulating means being arranged to meter separately the gas injected into said returning drilling mud at said spaced levels to lighten said drilling mud according to a program to reduce the hydrostatic head of said returning mud column while obtaining a straight line hydrostatic head versus depth curve whereby the weight of said mud within said conductor pipe is lessened to reduce the tensioning force required to support said conductor pipe in a body of water to prevent structural or buckling failures in said pipe and whereby the hydrostatic force of mud circulating within said borehole is substantially unaffected.

5. A method for reducing the forces tending to cause structural or buckling failures in a conductor pipe extending through a body of water from a surface facility to a subaqueous borehole including the following step:

- (a) injecting a compressed gas, lighter than the surrounding water, into said conductor pipe above said subaqueous borehole, at spaced intervals to lighten the effective weight of the returning drilling mud therewithin according to a program that will result in the curve of the hydrostatic head versus depth of said returning drilling mud approximating the curve of the hydrostatic head versus depth relationship for the surrounding water.

6. A method for reducing the forces tending to cause structural or buckling failures in a conductor pipe ex-

tending through a body of water from a surface facility to a subaqueous borehole including the following step:

- (a) injecting a compressed gas, lighter than the surrounding water, into said conductor pipe above said subaqueous borehole, at spaced intervals to lighten the effective weight of the returning drilling mud therewithin according to a program that will result in the curve of the hydrostatic head versus depth of said returning drilling mud in said conductor pipe being such that the hydrostatic head of the drilling mud in said conductor pipe is at all points along said conductor pipe less than the hydrostatic head of the surrounding water at the same depth.

7. A method for supporting a conductor pipe in tension in a body of water from a surface facility, said conductor pipe extending from said surface facility to a subaqueous borehole, to prevent structural or buckling failures in said conductor pipe, including the following step:

- (a) injecting into the lower end of said conductor pipe, filled with returning drilling mud, to lighten the effective weight of said drilling mud, approximately five cubic feet of free air per minute for every cubic foot of said drilling mud circulated per minute.

8. A method for supporting a conductor pipe in tension in a body of water from a surface facility, said conductor pipe extending from a surface facility to a subaqueous borehole, to prevent structural or buckling failures in said conductor pipe including the following step:

- (a) directing exhaust gas, from at least one combustion engine on said surface facility, into the lower end of said conductor pipe filled with returning drilling mud, to lighten the effective weight of said drilling mud.

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