United States Patent [19]

Bruce et al.

[11] **3,815,673**

[45] **June 11, 1974**

[54] **METHOD AND APPARATUS FOR CONTROLLING HYDROSTATIC PRESSURE GRADIENT IN OFFSHORE DRILLING OPERATIONS**

[75] Inventors: **George H. Bruce; William T. Ilfrey,** both of Houston, Tex.

[73] Assignee: **Esso Production Research Company,** Houston, Tex.

[22] Filed: **Feb. 16, 1972**

[21] Appl. No.: **226,843**

[52] **U.S. Cl.** **166/0.5,** 175/7, 175/72, 175/25

[51] **Int. Cl.** **E21b 7/12**

[58] **Field of Search** 175/25, 38, 5, 72, 48, 175/7, 50, 69; 166/0.5, 0.6

[56] **References Cited**

UNITED STATES PATENTS

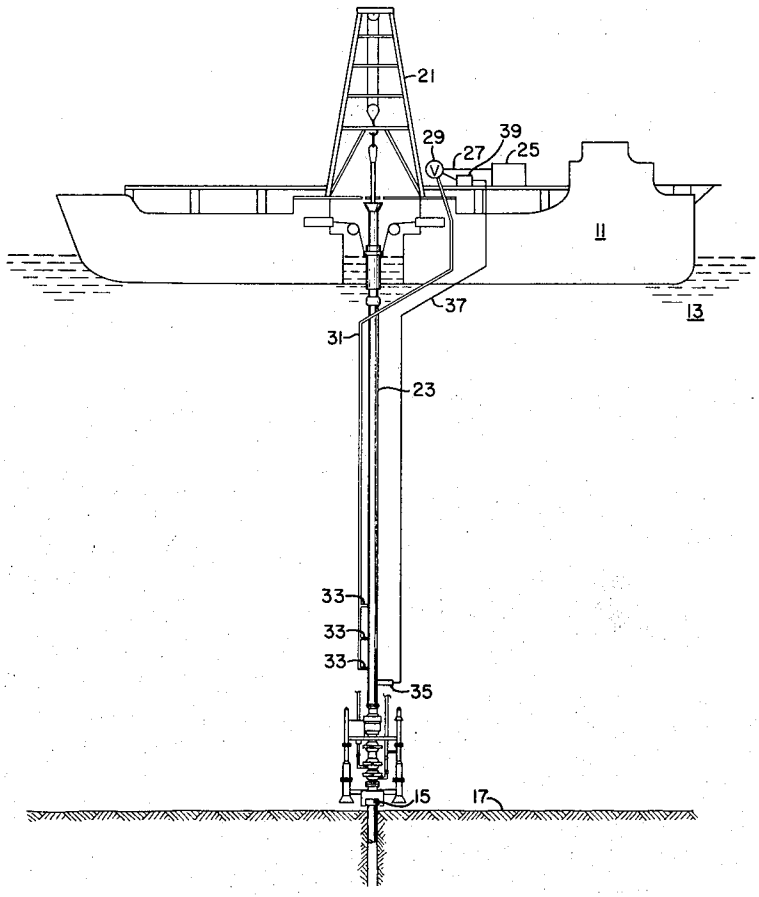
2,726,063	12/1955	Ragland et al.	175/69
2,808,230	10/1957	McNeill et al.	175/7
2,923,531	2/1960	Bauer et al.	175/7
3,434,550	3/1969	Townsend	175/5
3,459,259	8/1969	Matthews	175/7 X
3,595,075	7/1971	Dower	175/48
3,603,409	9/1971	Watkins	175/25

Primary Examiner—Henry C. Sutherland
Assistant Examiner—Richard E. Favreau
Attorney, Agent, or Firm—James E. Gilchrist

[57] **ABSTRACT**

An improved system for offshore drilling is disclosed which is particularly useful in those operations where a floating vessel is situated at the surface of a body of water and circulation of drilling fluid is accomplished by introducing drilling fluid into a drill string extending from the vessel into a borehole in the floor of the body of water and returning it through a separate conduit to the vessel. A surface detectable signal is generated which is proportional to the hydrostatic head exerted by the drilling fluid within the return conduit. Hydrostatic head of the drilling fluid within the return conduit is controlled in response to the signal, as by injecting gas into the conduit near its lower end, to regulate the hydrostatic head of the fluid in the borehole.

2 Claims, 3 Drawing Figures



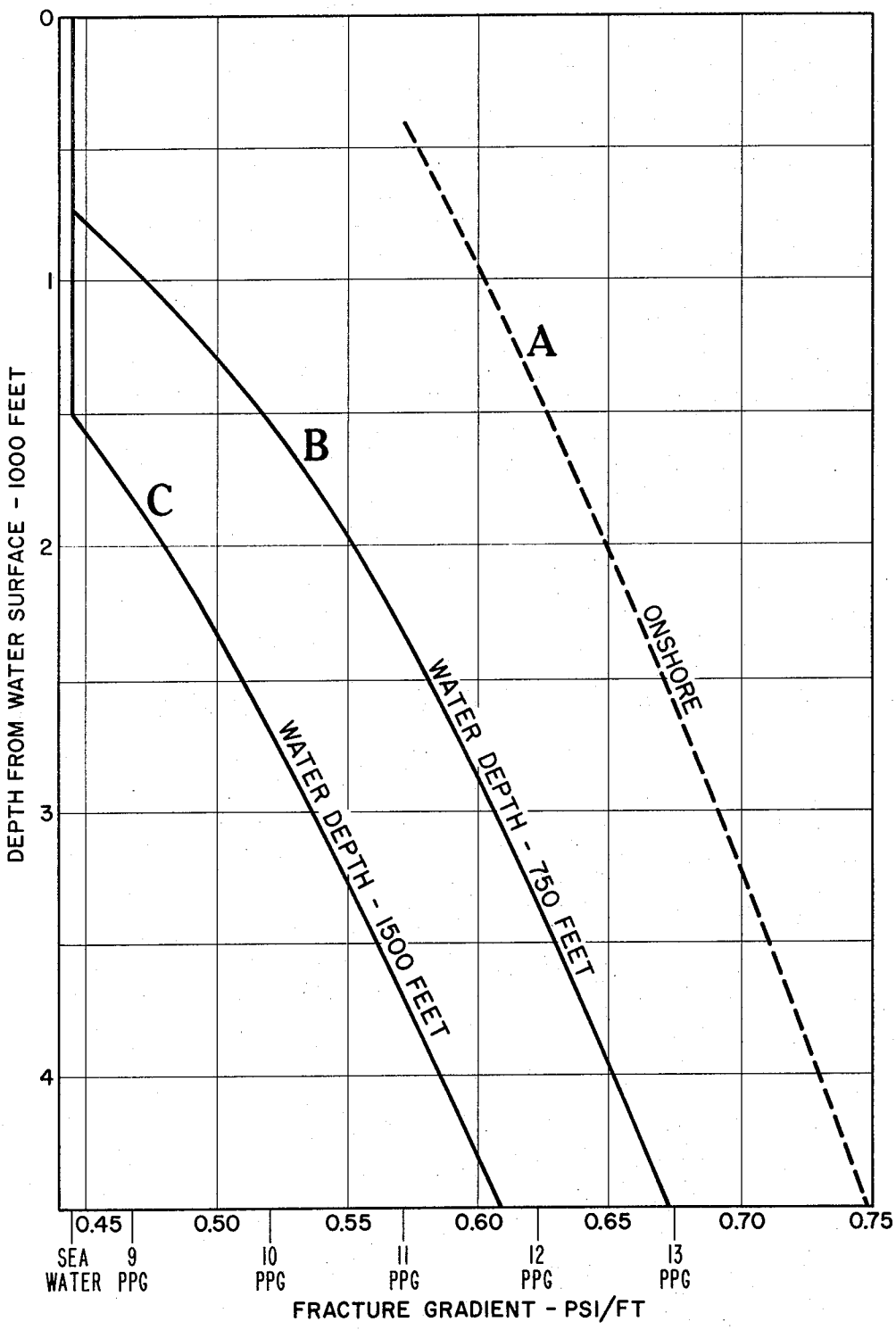

0
1
2
3
4
DEPTH FROM WATER SURFACE - 1000 FEET
A
B
C
ONSHORE
WATER DEPTH - 750 FEET
WATER DEPTH - 1500 FEET
0.45
0.50
0.55
0.60
0.65
0.70
0.75
SEA WATER
9 PPG
10 PPG
11 PPG
12 PPG
13 PPG
FRACTURE GRADIENT - PSI/FT

FIG. 1

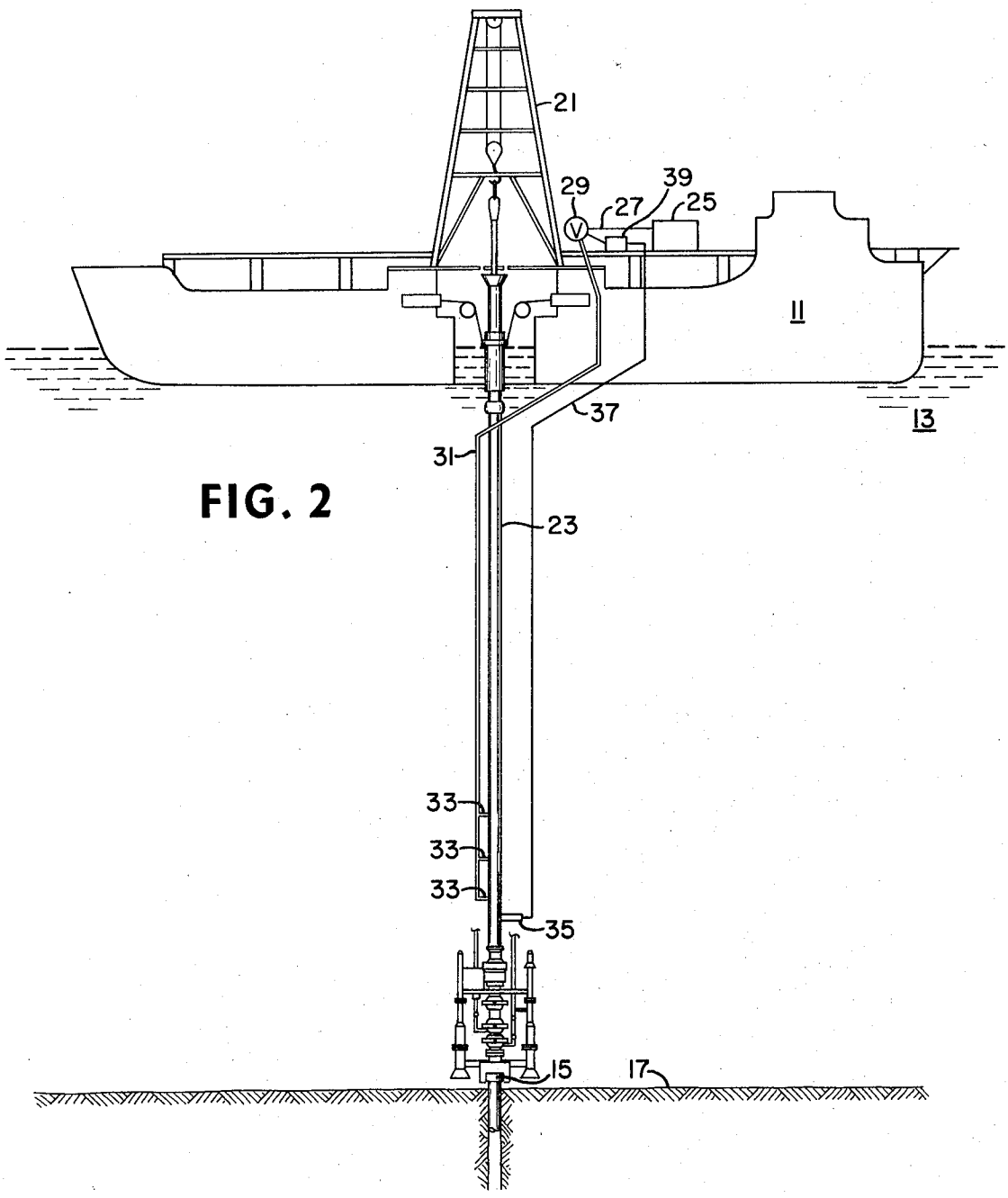


FIG. 2

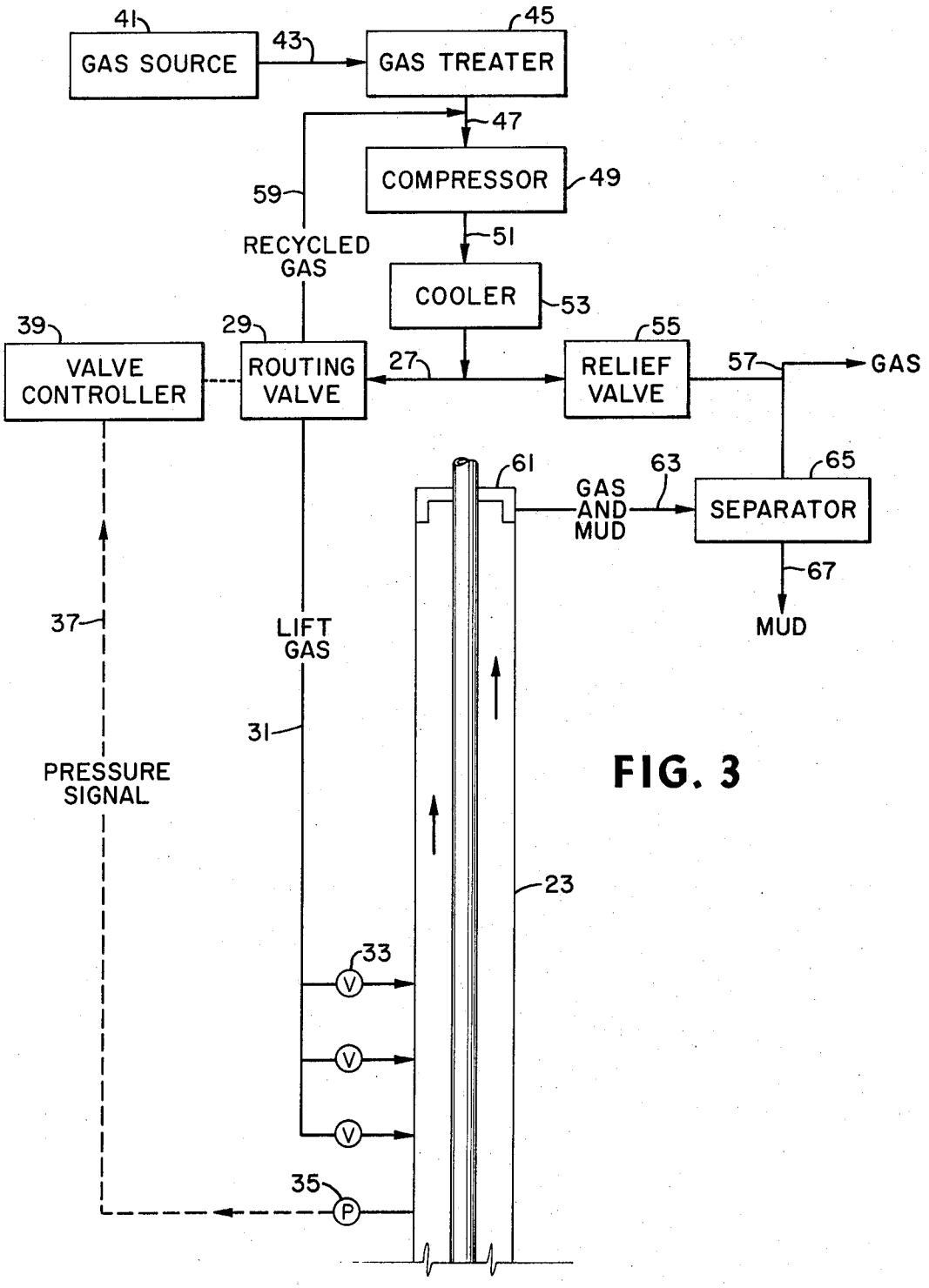

41
GAS SOURCE
43
45
GAS TREATER
47
COMPRESSOR
49
59
RECYCLED GAS
51
COOLER
53
39
VALVE CONTROLLER
29
ROUTING VALVE
27
55
RELIEF VALVE
57
GAS
61
63
GAS AND MUD
65
SEPARATOR
67
MUD
37
LIFT GAS
31
PRESSURE SIGNAL
23
33
V
V
V
35
P

FIG. 3

METHOD AND APPARATUS FOR CONTROLLING HYDROSTATIC PRESSURE GRADIENT IN OFFSHORE DRILLING OPERATIONS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an improved system for drilling from a floating vessel which involves monitoring and controlling the hydrostatic head of the drilling fluid returns to control bottom hole pressure.

2. Description of the Prior Art

In recent years the search for offshore deposits of crude oil and natural gas has been extended into ever deeper waters overlying the continental shelves. With increased water depths the conduct of drilling operations from floating vessels has become more prevalent since economic considerations militate against the use of bottom-founded drilling platforms commonly used in shallow water. In these operations the drill rig and associated equipment are positioned aboard a floating vessel which is stationed over the wellsite. The drill string extends from the vessel to a wellhead situated on the floor of the body of water and a separate return conduit, normally a riser pipe, is provided to permit circulation of drilling fluid.

Control of the influx of fluid from pressurized subsurface formations is an important aspect of any drilling operation. If uncontrolled, fluid influx can lead to a blowout and fire, frequently with catastrophic results in terms of loss of life, damage to property, and pollution of the seaway. Conventionally, well control is established by maintaining the density of the drilling fluid and thus the hydrostatic pressure exerted on the subsurface formations at a level sufficient to overcome formation pressures. At the same time, caution is necessary to assure that the density and hence pressure gradient of the column of fluid does not exceed the natural fracture gradient of the formation, i.e., the pressure gradient necessary to initiate and propagate a fracture in the formation.

In deep water, the natural fracture gradient of shallow formations is particularly critical factor. It is directly related to the bulk density of the sediments resting on top of the pressurized formation and thus at the floor of the body of water is for all practical purposes the pressure gradient of water. For a formation situated 500 feet below the floor of a body of water having a depth of 2,000 feet, the natural fracture gradient will be greatly influenced by the gradient of the overlying body of water. Because of the higher bulk density of rock, however, the fracture gradient rapidly increases with the depth of penetration into the sea floor and will not represent a serious problem after the first few thousand feet of hole are drilled.

During the drilling of the surface hole (the first few thousand feet) the hydrostatic head of the drilling fluid should not greatly exceed that of a column of salt water to minimize the possibility of formation fracture. On the other hand, normally pressured formations have a pressure similar to that exerted by a column of salt water corresponding to formation depth. It will therefore be apparent that in deep water, achieving a hydrostatic head high enough to control the well and yet low enough to prevent fracturing subsurface formations will require careful control of the pressure gradient of the drilling fluid.

In offshore operations controlling the density of the fluid as it is pumped into the well is not an entirely satisfactory approach since at normal drilling rates the drill cuttings suspended in the returning drilling fluid may sufficiently increase its density to yield a gradient exceeding normal fracture gradient. Heretofore, the only available system to assure a balanced condition in these circumstances was to greatly increase drilling fluid circulation rate or to reduce the rate of penetration; both practices are economically unattractive. A need therefore exists for a system for controlling the hydrostatic head of the drilling fluid within close limits without either increasing drilling fluid circulation rate or reducing the penetration rate.

SUMMARY OF THE INVENTION

The present invention permits close control over the pressure gradient of the drilling fluid at no sacrifice of penetration rate and with no increase in circulation rate and thus alleviates the difficulties encountered in deep water drilling which are outlined above. In accordance with the present invention the hydrostatic pressure exerted by the drilling fluid within the drilling riser or other return conduit is monitored and its density is regulated to control the hydrostatic head of the mud column and thereby assure sufficient hydrostatic pressure to counterbalance formation pressures without exceeding their fracture gradients.

The system of the present invention is particularly applicable to drilling operations wherein a floating vessel is situated at the surface of a body of water above a wellhead positioned on the floor thereof. Drilling fluid is introduced into a drill string that extends between the vessel and wellhead and is returned through a separate conduit. The apparatus of the invention includes a means mounted on the conduit for generating a signal proportional to the pressure therein and detectable at said vessel. The method involves monitoring the hydrostatic head of the fluid flowing within the conduit and regulating its density to control the hydrostatic head of the column of drilling fluid acting on subsurface formations. The pressure gradient of the fluid within the return conduit can be reduced by injecting gas into the conduit. The rate of gas injection is controlled in response to the pressure within the riser to maintain the hydrostatic head at a substantially constant level, thereby assuring the proper hydrostatic head will be maintained on formations exposed to the borehole.

It will theerefore be apparent that the present invention will permit the hydrostatic pressures exerted by drilling fluids and entrained cuttings to be closely controlled without any substantial reduction in drilling rate or increase in circulation rate. The present invention thus permits control of pressurized formations during normal drilling operations while reducing the danger of exceeding their fracture gradients and offers significant advantages over systems existing heretofore.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 depicts typical curves relating fracture gradient to formation depths beneath the water surface.

FIG. 2 is an elevation view, partially in section, of a floating drilling vessel provided with apparatus necessary to carry out the method of the invention.

FIG. 3 is a schematic flow diagram of a system for monitoring and regulating the hydrostatic head of the

drilling fluid within the return conduit in accordance with the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 is a plot of formation depth in thousands of feet versus the natural fracture gradient expressed both in psi/ft and as an equivalent mud density in lbs/gal (ppg). The curves shown are for a particular geographic area but illustrate the general relationship between water depth and formation fracture gradient. It will be apparent from an inspection of FIG. 1 that for any particular depth from the water surface, the fracture gradient decreases markedly as water depth increases.

Curve A relates the fracture gradients of formations encountered onshore to depth. These range from 0.60 psi/ft at 1,000 ft up to about 0.69 psi/ft at 3,000 ft. Curve B is for similar strata at a water depth of 750 ft. The fracture gradient is thus that of sea water, about 0.44 psi/ft, for depths to 750 ft. A formation buried under 1,000 ft of sediments is 1,750 ft below the water surface and will be noted to have a fracture gradient on the order of 0.54 psi/ft. The gradient at 3,000 ft beneath the sea floor (3,750 ft below the water surface) is 0.64 psi/ft. Curve C represents identical sediments under 1,500 ft of water. The natural fracture gradient for a formation under 1,000 ft of sediments corresponds to a depth of 2,500 ft and will be noted to be 0.51 psi/ft, corresponding to a mud weight just under 10 ppg. At 3,000 ft of penetration, the fracture gradient is 0.61 psi/ft. It will therefore be apparent that for any particular depth of penetration into the substrata, the fracture gradient decreases as water depth increases.

The importance of the decrease in fracture gradient with water depth can be demonstrated by an example comparison of the hydrostatic pressure required to maintain well control to that which will fracture the formation. A normally pressured subsurface formation can be anticipated to have a formation pressure equivalent to the pressure exerted by a column of salt water having a height equal to formation depth. A gas formation 1,000 ft beneath the floor of a 1,500 ft body of water could therefore be expected to have a pressure equal to the product of the salt water gradient and the depth of the formation beneath the water surface or about 1,110 psi and a drilling fluid having a salt water gradient (0.445 psi/ft, or about 8.5 ppg) could be expected to balance the formation pressure. It is normally desirable to drill with a fluid having a degree of overbalance, i.e., exerting a hydrostatic head greater than formation pressure. On the other hand, the fracture gradient at this depth is 0.51 psi/ft, which corresponds to a bottom hole pressure of 1,275 psi. Thus the pressure exerted by the mud must be kept between 1,110 and 1,275 psi. This in turn dictates a mud density between 8.5 ppg, corresponding to the salt water gradient and 9.8 ppg which could be expected to break down the formation with attendant loss of drilling fluid and well control. While compounding a drilling fluid which will have a density in this range is a simple matter, maintaining it at the required level during the course of the drilling operation is a somewhat more complex problem.

By and large, shallower formations permit more rapid penetration by the bit than do deeper formations. Accordingly, the surface hole is normally drilled at a relatively rapid rate. At the same time, rapid drilling leads to an increase in the volume of drilled solids in the mud, substantially increasing its density. Although not a problem onshore or at shallow water depths, because of the decreased fracture gradient, this increase in density creates problems in deep water. The difficulties could of course be overcome by drilling at reduced rates and simultaneously increasing the rate of circulation, thereby assuring that the drilling fluid density remains within the critical range. This approach is however economically very unattractive in view of the daily expense of maintaining drilling equipment at the wellsite.

An alternative approach is to drill at a rapid penetration rate and at the same time reduce the bottom hole pressure of the drilling fluid by injecting gas or other low density material into the riser to lighten the mud. At the same time, however, a gas injection program undertaken in deep water requires careful control to assure that the hydrostatic head of the drilling fluid remains between that necessary to control the well and that which would result in a fracturing of the formation. It is therefore an important aspect of the present invention to monitor the pressure exerted by the drilling fluid within the return conduit and to adjust the density of the fluid therein to control bottom hole pressure. Control of fluid density is preferably accomplished by injecting gas into the riser near the lower end at a rate regulated in response to the pressure therewithin to maintain the total hydrostatic head of the drilling fluid acting on a subsurface formation within the range necessary to assure control of the well without fracturing the formation.

FIG. 2 shows a drilling vessel **11** floating on a body of water **13** and equipped to carry out the method of the present invention. A wellhead **15** is positioned on the floor **17** of the body of water. A drill string **19** is suspended from derrick **21** mounted on the vessel and extends between it and the wellhead. Drilling fluid is pumped down the string of drill pipe through the bit and into the borehole and returns to the vessel via a return condit shown as drilling riser **23.** A high pressure gas source **25** is situated aboard the vessel. Injection conduit **31** extends from the control valve down the length of the riser to a level near the wellhead. One or preferably a plurality of gas lift valves **33** are positioned between the injection line and the drilling riser. The lift valves are normally preset to open at a given differential pressure. A pressure sensor **35** is shown positioned near the lower end of the drilling riser and arranged to sense riser internal pressure. It may for example be a pressure transducer which generates an electrical signal proportional to pressure within the return conduit. The signal is conducted to the surface by means of electrical conductor **37** extending between the pressure transducer and the drilling vessel. It may be directed to controller **39** which controls the position of routing valve **29** in response to the amplitude of the pressure signal to regulate the rate at which gas is introduced into the lower portion of the drilling riser. By properly adjusting the response characteristics of the valve controller, the pressure gradient of the fluid within the drilling riser can be closely controlled.

FIG. 3 is an exemplary flow diagram of apparatus which can be used to implement the method of the invention. An inert gas source is designated by numeral **41** and is preferably engine exhaust gas or the product

from an inert gas generator. Exhaust gas is routed through conduit **43** to gas treater **45.** Nitrogen oxide and water are separated from the source gas and the residue, which consists primarily of nitrogen, carbon dioxide and water, is piped through conduit **47** to compressor **49.** The gas is then compressed through stages, as required, to sufficiently increase its pressure. For depths of 1,000–2,000 ft, 1,500 psi will normally suffice. The high pressure gas is conveyed to cooler **53** which condenses any residual water and cools the compressed gas to about 100°F. Normally, the dry, high pressure gas passes from treating unit **53** via line **27** to routing valve **29.** In the event of excess pressure, however, release valve **55** opens and discharges the gas through exhaust line **57,** returning the inert gas to the atmosphere. Under normal pressure conditions, the release valve remains closed and routing valve **29** diverts part of the gas down injection line **31** to lighten the drilling fluid and recycles the remainder through conduit **59** leading back to the compressor. The percentage of gas diverted into the riser is controlled by valve controller **39** in response to a surface detectable signal proportional to pressure within the riser which is generated from pressure sensor **35** situated near the base of the riser and may, for example, be conducted to the vessel by means of electrical conductor **37** leading to the valve controller. The signal could alternatively be transmitted acoustically, pneumatically or by other means as well.

High pressure gas routed into injection conduit **31** travels downwardly and into the riser through differential-pressure actuated gas lift valves **33.** These valves are preferably vertically spaced to assist in unloading the riser whenever drilling operations have been interrupted for a period of time. Gas is injected into the interior of the conductor pipe in the annulus surrounding the drill pipe and the lift gas and drilling fluid flow upwardly to rotating drilling head **61** which diverts the gas-mud mixture away from the drill floor. Both gas and mud are diverted through conduit **63** to separator **65** wherein the inert gas is separated from the mud as by means of gravity segregation. The gas is exhausted to the atmosphere via exhaust conduit **57** while the mud is returned through line **67** to the mud pits for recirculation.

What is claimed is:

1. In a method of drilling wherein a floating vessel is situated at the surface of a body of water and drilling fluid is introduced into a drill string extending from the vessel into a borehole in the floor of the body of water and returned to the vessel through a separate conduit which conduit is provided with means for injecting a gas thereinto near its lower end, the improvement comprising measuring the hydrostatic pressure of the drilling fluid within said return conduit beneath the gas injection point and adjusting the pressure gradient of the fluid contained within the return conduit to maintain the hydrostatic pressure of the drilling fluid within the borehole at a level sufficient to counterbalance formation pressure without exceeding its fracture gradient.

2. The method of claim **1** wherein said gas is an inert gas.

* * * * *