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CROSS REFERENCE - SEARCH ROOM

March 14, 1967 T. R. REINHART 3,308,894

MONITORING SYSTEM FOR GASEOUS FLUID DRILL BOREHOLES

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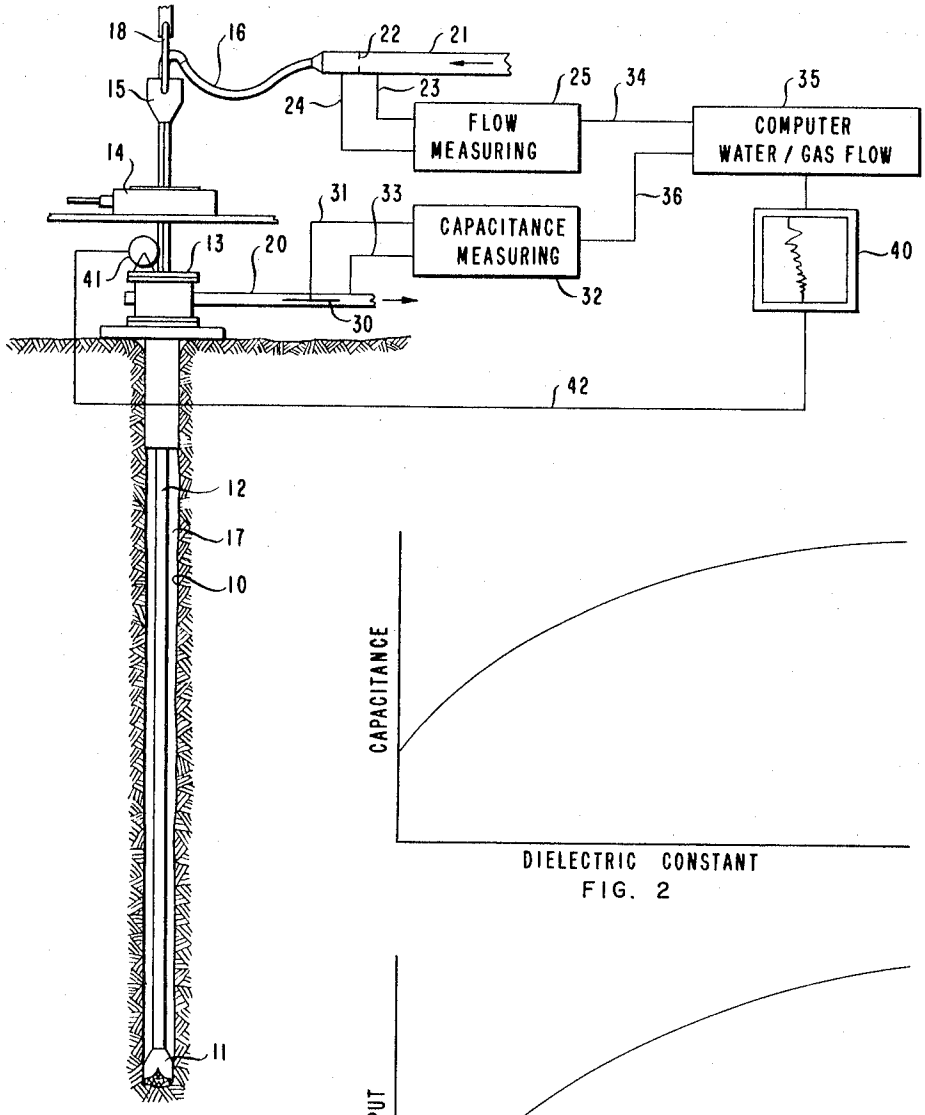


FIG. 1

FIG. 2

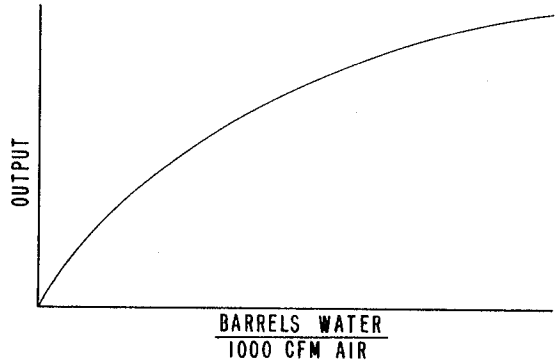


FIG. 3

INVENTOR:
T. R. REINHART
BY: Thomas E. Bibler
HIS ATTORNEY

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MONITORING SYSTEM FOR GASEOUS FLUID DRILL BOREHOLES

Tom R. Reinhart, New Orleans, La., assignor to Shell Oil Company, New York, N.Y., a corporation of Delaware

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This invention pertains to the drilling of boreholes and more particularly to the drilling of boreholes by means of a rotary drilling rig using a gaseous fluid as the circulating medium.

The use of a gaseous fluid in rotary drilling operations is becoming increasingly important as a result of the high penetration rates achieved with a gas drilling procedure. Normally either compressed air or compressed natural gas is used as the circulating fluid and the technique is commonly referred to as air drilling. This term will be used hereafter to refer to both the use of compressed natural gas, compressed air and other compressed gases. While high penetration rates are achieved with an air drilling technique, the technique involves several problems. The greatest problem occurs when water-bearing or other liquid-bearing formations are penetrated. The penetration of a water-bearing formation causes the drill cuttings to form a mud which plasters itself to the drill pipe and the borehole wall, thus preventing the compressed air from removing the drill cuttings from the borehole. In addition, when a water-sensitive shale formation has been penetrated prior to the penetration of a water-bearing formation, the water that flows into the borehole is moved into contact with the shale formation by the circulating stream of air. The shale absorbs the water, swells and tends to slump or slough into the borehole. Such a sloughing of shale is apt to result in a stuck drill pipe and a lost hole.

In the past it has been traditional to visually observe the discharge pipe at the surface of the borehole to ascertain when the borehole had penetrated a water-bearing formation. When an air drilling operation is proceeding normally the discharge at the surface will cause the drill cuttings to form a dust-like cloud, which is referred to as "dusting." The normal procedure is to observe the discharge and note when the dusting stops. This has traditionally been taken as the time when a water-bearing formation has been penetrated. After a water-bearing formation has been penetrated various techniques are used in an effort to re-establish the transport of the drill bit cuttings to the surface. One technique is to attempt to cause the mud and water deposits to form a foam which is then transported to the surface by the compressed air. This is known as foam or mist drilling. Also, various materials may be introduced into the borehole in an attempt to seal off the water-bearing formation.

In addition to the above visual technique for detecting when a water-bearing formation has been penetrated attempts have also been made to measure the change in temperature of the discharge air stream at the surface. The theory behind this attempt has been that the temperature will fall as a water-bearing formation is penetrated due to the evaporation of the water. While this is a possible method for determining when the borehole has penetrated a water-bearing formation, it provides inaccurate results since a considerable amount of water must penetrate into the borehole before a measurable temperature change occurs in the discharge air stream. Other factors also influence the temperature of the discharge air stream such as air flow rate, depth of the hole and ambient temperature.

While various techniques are available for treating shale formations that are susceptible to water damage, the treatments are more successful if they can be performed

before a water-bearing formation is penetrated. This requires a forewarning of when the water-bearing formation will be encountered. For example, in the copending application of H. C. H. Darley, entitled "Air Drilling Shale Control," Ser. No. 270,164, filed Apr. 3, 1963, now Patent No. 3,259,189, there is disclosed a method for treating shale formations to prevent their crumbling under the influence of water. As explained in this copending application the technique is best applied before the water-bearing formation is encountered. In this case the shale formations are stabilized and the water-bearing formation can then be penetrated and drilled with less detrimental results to the shale formations.

In view of the above problems this invention is directed to a method for determining the variations with depths of the rate at which water is released by the earth formations encountered while drilling with a substantially waterfree gaseous drilling fluid. More particularly the invention comprises a method in which one measures the variation with time of the water content of drilling fluid and solids that are exhausted from the borehole. The measuring of the water content is done at a sensitivity which is responsive to the water content while the drilling fluid and solids are still dusting as they are discharged into the air. The measuring is also sensitive to water that is contained in the pore spaces of crushed rock and the like. Further since the water being returned to the surface may be in the form of water in the pore space of the crushed rock being returned neither a visual observation or temperature measuring system would detect the water. Other factors also influence the temperature of the discharge air stream such as air flow rate, depth of the hole and ambient temperature. Concurrently with the water content monitoring the quantity of drilling fluid being circulated is also measured. The measurements of the water content of the discharge stream plus the quantity of drilling fluid being circulated are then combined to obtain the amount of water being returned to the surface by the action of the drilling returns in volume flow rates such as gallons per minute. From this information one can then determine when a water-bearing formation has been penetrated. In fact, by making the measurements at such a sensitivity, it is often possible to predict when the water-bearing formation is likely to be encountered. This is true as minute amounts of water from a water-bearing formation tend to migrate into the porous formations overlying the water-bearing formations. By using measurement systems capable of detecting and measuring these minute amounts of water due to the proximity of a true water-bearing formation, a warning of the proximity of the water-bearing formation may be obtained. Thus, by the above type of measurements, one is given forewarning of when the water-bearing formation will be encountered and various protective measures may be instituted, as for example the techniques described in the above-referenced copending application, before any significant amount of water has migrated into the borehole.

The method of this invention will be more easily understood by those skilled in the art from the following detailed description as when taken in conjunction with the attached drawings in which: FIGURE 1 shows in block diagram form a preferred embodiment of this invention; FIGURE 2 is a graph of the dielectric constant and capacitance for a typical return stream for a gas drilling operation; and FIGURE 3 is a graph of water per volume of air with relation to the output signal of a capacitance probe.

Referring now to the attached figure, there is shown a borehole **10** that is drilled by a rotary bit **11**. The drill bit **11** is coupled to a drill string **12** which is rotated by means of a rotary table **14** at the surface. This is a

conventional type of drilling structure well-known to those skilled in the art. The surface of the wellhead is closed by wellhead fitting **13** that contains the blowout preventers and other equipment normally associated with a rotary drilling operation. The top of the drill string **12** is coupled or connected to a swivel connection **15** that has a bail **18** in order that the drill string may be raised or lowered by the drilling rig not shown in the attached figure. The swivel connection is coupled by means of a flexible hose **16** to a conduit **21** that supplies the compressed substantially waterfree gaseous fluid for the drilling operation. The compressed fluid travels down the drill string **12** to the drill bit **11**. At the drill bit **11** it cools the bearings in the drill bit and then circulates out into the annulus **17** between the drill string **12** and the borehole **10**. The compressed gaseous fluid in circulating out through the drill bit **11** picks up the formation cuttings and transports them up the borehole **10**. At the surface gaseous fluid and entrained formation cuttings are discharged through a conduit **20** which communicates with the interior of the wellhead **13**. The drill bit and the formation cuttings are discharged from the end of the conduit **20** into a suitable pit or other enclosure not shown in the attached figure.

Positioned or mounted in the conduit **21** is a flow measuring device **22**. The flow measuring device may take various forms as for example a flow measuring orifice or venturi as shown. In the case of an orifice it is necessary to measure the pressure at the point **23** on the upstream side of the orifice and the pressure **24** on the downstream side of the orifice. The difference in the two pressure measurements at points **23** and **24** is then related to the quantity of gaseous fluid passing through the orifice **22**. The two pressure measurements are supplied to a flow measuring circuit **25** which measures or detects the pressure differential and converts it to a related flow signal. Equipment for measuring flow rates in this manner is well known to those skilled in the art and readily available. Of course, other flow measuring devices could also be used as for example, one may use a mass flow meter whose output varies with the mass quantity of fluid flow through the conduit **21**. Also, pressure measurements could be made in the conduit **21** and the resulting pressure differentials converted to a flow rate. The important feature of the present invention is that the rate of flow of the compressed gaseous fluid with time is measured.

Disposed in the conduit **20** is a means for measuring the water content of the stream of gaseous fluid and entrained formation cuttings being discharged. While various means may be used for measuring the water content the means used must be sensitive to slight changes in the water content. As explained above, this invention depends on the ability to measure a water content in the stream even when the discharge stream is still dusting as the term is used in the air drilling art. A device having suitable sensitivity for measuring the water content is a capacitance type probe as shown in the attached figure. This probe consists of a central electrode **30** which is insulated from the conduit while the wall of the conduit **20** thus forms the second electrode of the capacitor. The central electrode **30** is coupled by means of a lead **31** to a capacitance measuring circuit **32** and the wall of the conduit **20** is also coupled to the capacitance measuring circuit **32** by a lead **33**. The capacitance measuring circuit **32** measures the capacitance of the capacitor formed by the probe **30** in the wall of conduit **20**. This capacitance of course will vary as the dielectric constant of the material flowing in the conduit **20** varies. As will be explained hereinafter the largest change in the dielectric constant is caused by the water content of the stream. In fact a slight change in the water content has at least eight times the effect as a similar change in any of the mineral or other liquid contents of the stream. The flow measuring circuit **25** is coupled by means of a lead **34** to a computer **35** that also receives a signal from the capacitance measuring circuit **32** by means of a lead **36**. The computer **35** is designed to accept the two signals representing the rate of flow of the gaseous fluid and the water content of the discharge stream and compute the water flow rate of the water being transported to the surface by the drilling fluid. The signal from the computer **35** is recorded on a strip chart recorder **40** that is driven at a speed related to the depth of the borehole **10**. The depth of the borehole can be determined by various measuring devices as for example, a sheave **41** rotated by the travel of the drill string **12** may supply an electrical signal related to the depth of the borehole. The electrical signal is supplied to the chart recorder **40** by means of a lead **42**.

In addition to the above, the chart recorder **40** can be provided with various warning devices, as for example, audible signals that are actuated whenever the amplitude of the signal from the computer **35** exceeds a preset value. In this way, the personnel operating the drilling rig will be appraised of the fact that the borehole is entering or about to enter a water-bearing formation.

Although this capacitance type measuring device may be used for monitoring the discharge stream, a more suitable device and associated circuit is shown and described in copending application of T. R. Reinhart entitled "Probe Assembly for Capacitance Type Monitoring Device," Ser. No. 362,375, filed Apr. 24, 1964. When this capacitance probe is used, capacitance will vary with the dielectric constant of the discharge stream as shown in FIGURE 2. From FIGURE 2 it is seen that the capacitance increases rapidly at the start and then approaches an upper limit asymptotically. The measured capacitance can then be converted to barrels of water per thousand cubic feet per minute of air by means of a suitable calibration as shown in FIGURE 3. Again it should be noted that the curve starts at a zero value and then approaches an upper limit asymptotically. The curve has a shape similar to the curve shown in FIGURE 2 and thus varies with the measured capacitance of the probe **31**.

The influence of water on the dielectric constant of the discharge stream is illustrated by following the table of dielectric constants for various materials commonly encountered while drilling a borehole:

Dry air at 113° F.	1.000247
Methane	1.000944
Crude oil (water free)	2.15–2.35
Dry sand	2.5
Granite	7–9
Diorite	8–9
Sandstone	9–11
Basalt	12
Water (liquid)	80

The above values illustrate the sensitivity of a capacitance measuring probe for detecting water in the discharge air stream.

While capacitance measurements are preferred, other methods may be used for measuring the water in the discharge stream. For example, it would be possible to periodically collect a sample of the discharge stream, weigh the sample, dry the sample and then reweigh the sample to determine the loss of weight. Also, chemical analysis of the discharge stream could be used to measure the water content.

The results of the above technique for air drilling of boreholes is illustrated in the following example. During the drilling of a well that was eventually extended to more than 17,000 feet, the upper section of the borehole was drilled to hole sizes of 26 and 17½ inches and casing string run and cemented to a depth of 5700 feet. The borehole was extended by air drilling at a hole size of 12¼ inches while circulating about 1800 cubic feet of air per minute at a pressure of about 100–180 pounds per square inch. During the air drilling operation, measure-

ments were made of the variation with time of the water content of the discharge air stream, the amount of air being circulated and the depth of the borehole. The combination of the data from these measurements indicated that at a depth of 6392 feet a significant increase occurred in the amount of water that was being imparted to a unit volume of the gas and solids being discharged from the earth formations. Since the hole was continuing to dust, that is the exhausting air and solids contained enough fines to form a dust cloud near the end of the discharge conduit **20**, drilling was continued for another 26 feet to a point at which it was desirable to run a logging survey. By the time drilling was resumed, water had accumulated in the borehole and the air returns were dust free; that is, there was no discharge of rock or dust in the discharge from the end of the discharge conduit **20** to create a dust cloud. The indication of the depth of the water-bearing formation that was provided by the increase in the water content of the gas returns was substantiated by the driller's report of encountering a broken formation at 6392 feet and was confirmed by the fact that water production ceased from this interval after water shutoff treatment of melamine formaldehyde. In this treatment the formation was plugged by injecting liquid resin and allowing it to cure to a solid within the pores of the formation.

From this example, it is seen that the method of this invention indicated that a water-bearing formation was about to be encountered. Thus, it would have been possible to pretreat the borehole walls prior to its drilling and prevent the problems that might arise once the water-bearing formation has been penetrated and water has entered the borehole. Also, the knowledge of where water was first encountered can be utilized in determining the upper boundary of the zone to be plugged in order to prevent the inflow of water.

As indicated above, the important features of this invention are the measurement of the water content of the discharged gaseous fluid and drill cuttings with time, the measurement of the quantity of gaseous fluid supplied to the borehole with time and the measurement of the depth of the borehole with time. From this information one then computes the quantity of water being returned to the surface as a function of time or depth. When there is an increase in the water being returned to the surface by the gaseous fluid it is an indication that the borehole is about to encounter or has already penetrated a water-bearing formation. As indicated in the example set forth in the above specification it was possible to drill an additional 26 feet of borehole while the discharge line continued to dust after the method of this invention had indicated that the water formation was to be encountered. Accordingly, it is seen that the prior methods of visual observation of the discharge air stream is inadequate and provides information too late to take effective corrective measures.

I claim as my invention:

1. A method for improving air drilling of boreholes in which circulation of the drilling air stream is down the drill string and up the annulus between the drill string and the borehole wall, the improvement comprising the steps of:

drilling the borehole while circulating air to return the formation cuttings to the surface;

monitoring at the surface the dielectric constant of the return fluid and solids stream to determine the water content thereof;

halting the drilling when the water content of the return fluid and solids stream raises above a preset background level;

treating the formation to shut off the flow of water and continuing to drill the borehole.

2. A method for improving air drilling of boreholes in which circulation of a drilling air stream is used to return the formation cuttings to the surface, the improvement comprising:

measuring the variations with time of the water content of the drilling fluids and solids exhausting from the borehole at a sensitivity responsive to variations in the water content of drilling fluid and solids that are capable of suspending the drilling fluids and solids as dust in the air into which they are discharged;

concurrently measuring the variations with time of the amount of drilling fluid that is circulated and the variations with time of the depth of the borehole; and

combining the data from said measurements to provide an indication of the variations with depth of the amount of water that is imparted to the drilling fluids and solids by the earth formations that are being encountered by the borehole.

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CHARLES E. O'CONNELL, *Primary Examiner.*

R. E. FAVREAU, *Assistant Examiner.*