Nov. 7, 1950 J. T. HAYWARD 2,528,956

DETECTION OF WASHOUTS IN ROTARY DRILLING STRINGS

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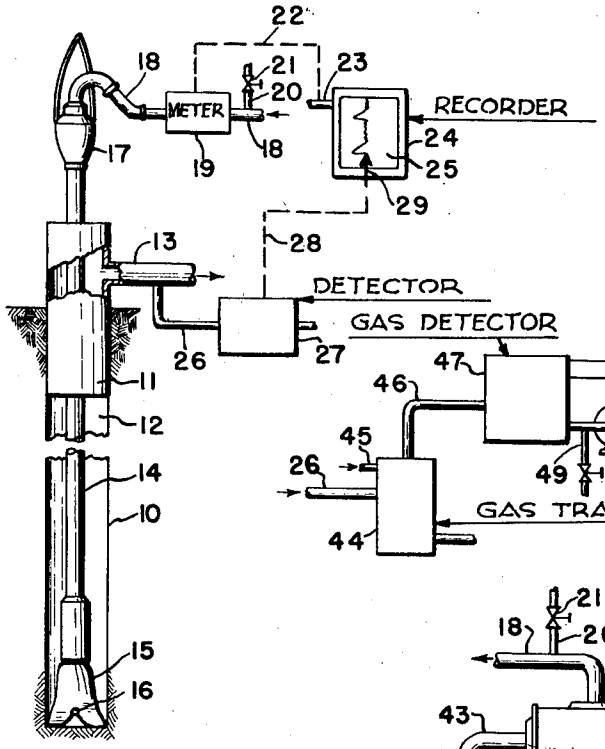


FIG. 1

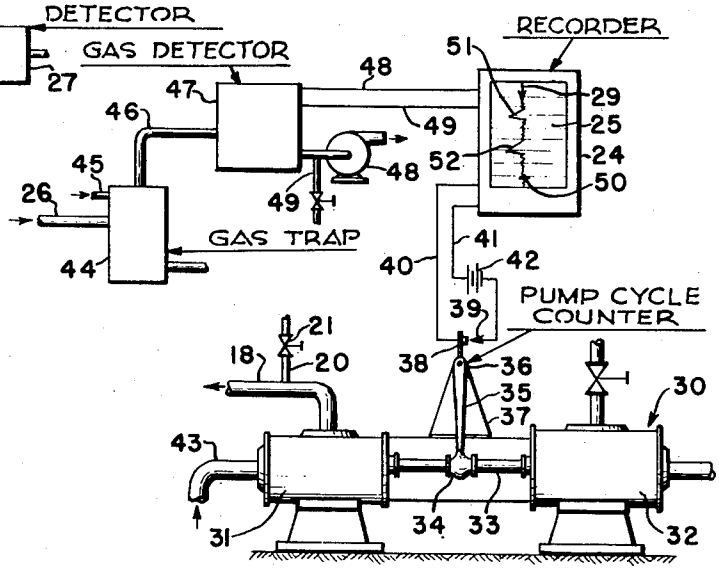


FIG. 2

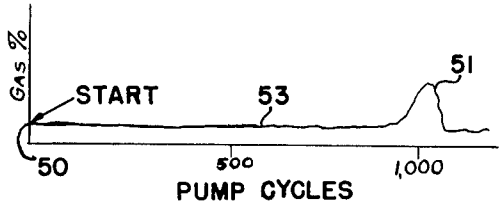


FIG. 3

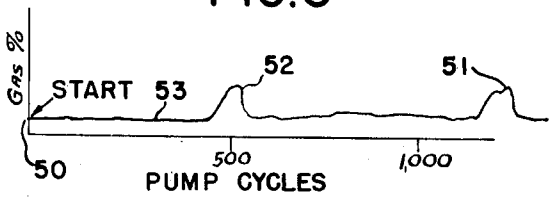


FIG. 4

JOHN T. HAYWARD
INVENTOR.

BY R. L. Werlein

ATTORNEY

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DETECTION OF WASHOUTS IN ROTARY DRILLING STRINGS

John T. Hayward, Tulsa, Okla.

Application September 19, 1947, Serial No. 774,946

2 Claims. (Cl. 73—40.5)

1

This invention relates to a method and apparatus for detecting wash-outs in rotary drilling strings and particularly to a method of detecting incipient wash-outs in such strings.

In the ordinary course of drilling a well, such as an oil or gas well, by the rotary method, a hydraulic fluid, such as a mud fluid, consisting ordinarily of a suspension of clay or earthy solids in water, is forced down through a string of hollow drill pipe to the bottom of the well, where it is discharged from the drill pipe through holes in the bit, commonly known as the "eyes," thence upwardly through the annular space between the drill pipe and the wall of the well bore to the surface of the ground.

Such mud fluids are normally very abrasive in character and, under the high pressures normally required to effect the circulation of fluid through the well, should a crack or pin hole be present or develop in the wall of the drill pipe, or should there be a slight leak in any of the threaded connections between sections of drill pipe, the mud fluid will be forced through such defective spots and by its abrasive action under the high pressure, will rapidly enlarge the opening until so much of the pipe metal is eroded away that the pipe is severed or parts of its own weight at the point of erosion. This condition is commonly referred to as a "wash-out" and results in the loss of the lower part of the drilling string in the well requiring so-called "fishing jobs" to recover this portion from the well. Fishing jobs are expensive, time-consuming, and in extreme cases may even cause loss of the well or at least may require that the well be "side-tracked" past the un-recovered pipe and re-drilled for a substantial portion of its depth. A very large percentage of all fishing jobs in rotary drilling are the result of wash-outs, and it will be evident, therefore, that any method which will warn against such wash-outs before they have progressed to the point of disruption of the drilling string will be of great value to the industry.

In Hayward Patent No. 2,290,179, issued July 21, 1942, there is described a method and an apparatus for detecting such incipient wash-outs. That method employs detection of the change in rate of a direct-acting pump, normally used to circulate the drilling mud through the well, as a means for warning of the incipiency of a wash-out. That patent discloses that a change of pump rate occurs when the drilling fluid flowing down inside the drill pipe is forced through a crack or leak in the pipe, the resistance to the discharge of the pump at the surface being thereby decreased

2

causing the pump to speed up in order to maintain constant discharge pressure.

This method has gone into extensive commercial use and has proven very successful. However, while it serves very adequately as a warning of the incipiency of a wash-out, it does not locate the point in the string where the leak is located. Accordingly, when in response to a warning given by the change in pump rate, the drilling string is withdrawn, the drillers must closely examine each section of drill pipe as it is withdrawn from the well in order to locate the point of leakage in order that a new section of drill pipe may be substituted therefor or other changes made as may be necessary to obviate the condition. This is very often difficult to do because the drilling string is usually heavily coated with viscous drilling mud and the point of leakage may be extremely small and, therefore, difficult to find.

Accordingly, it is a principal object of this invention to provide a method by which incipient wash-outs may not only be detected but also located as to their position in the drilling string.

Another important object is the provision of a method employing an indicating medium which is introduced into the stream of the drilling fluid for circulation therewith, which may be readily detected upon its return to the surface in a manner whereby the existence and position of a leak or incipient wash-out may be determined.

A more specific object is the provision of a method employing an indicating medium which, upon its return to the surface and detection there, is rendered ineffective for further detection of wash-outs to thereby avoid false indications on recirculation of the drilling fluid.

Still another object is the provision of apparatus for performing the method in accordance with this invention.

Other and more specific objects and advantages of this invention will become apparent from the following detailed description, when read in conjunction with the accompanying drawings which illustrate useful embodiments of the apparatus for practicing the method in accordance with this invention.

In the drawings:

Fig. 1 is a more or less diagrammatic illustration of an assembly of apparatus for performing the method in accordance with this invention, shown in operative relationship to the drilling fluid circuit of a well;

Fig. 2 is a diagrammatic illustration of an assembly of apparatus in accordance with a specific embodiment of this invention;

Fig. 3 is a representation of a chart obtained by the method and apparatus in accordance with this invention in the absence of any wash-outs; and

Fig. 4 is a chart similar to Fig. 3 obtained where an incipient wash-out is present and showing an indication of its presence and position in the drilling string.

Referring to the drawings and to Fig. 1 in particular, the numeral 10 designates a well bore being drilled by the conventional rotary method and equipped with a surface casing 11 lining the upper end thereof. Casing 11 is provided with an outlet pipe 13 adjacent its upper end. A conventional hollow drilling string 14 extends into the well from the surface and is equipped at its lower end with the usual bit 15, provided with eyes 16, which provide communication between the interior of the drilling string and the annular space 12 between the drilling string and the wall of the well bore. The upper end of the drilling string is connected to the usual rotary swivel 17, through which drilling fluid is introduced through a pipe 18 by conventional mud pumps (not shown). A fluid meter 19 of any suitable construction is inserted in pipe 18 for metering the flow of drilling fluid into the well. A branch pipe 20, fitted with a valve 21, is connected into pipe 18 for the introduction of a suitable leak indicating medium, to be described hereinafter, into the stream of drilling fluid entering the well. The broken line 22 indicates a suitable and conventional electrical or other type connection from meter 19 to the chart drive 23 of a conventional recorder 24 preferably of the strip-chart type, the chart being indicated by the numeral 25. Outlet pipe 13 from the surface casing is provided with a branch pipe 26, which leads to a detector 27 of any suitable and conventional form (to be more fully described hereinafter), for detecting the indicating medium in the drilling fluid returning to the surface through annular space 12, and broken line 28 indicates a conventional electrical or other suitable connection from detector 27 to the pen arm 29 of recorder 24.

The above assembly of apparatus is employed in the following manner in performing the method in accordance with this invention: In the usual course of the drilling operation, drilling fluid is pumped through pipe 18, swivel 17, down through the interior of drilling string 14 and out through eyes 16 of bit 15 into the annular space 12, whence it flows upwardly to the surface, discharging from surface casing 11 through outlet pipe 13 to the usual mud ditches and suction pit (not shown) from which it is subsequently returned to pipe 18 for repeating its cycle through the well. The fluid passing through pipe 18 will be metered by meter 19 and the volume of fluid recorded by meter 19 will be transmitted to chart drive 23 by connection 22 in such a manner as to move chart 25 at any suitable rate per unit of volume of drilling fluid passing through meter 19 into the well, for example, one inch for every ten barrels of fluid entering the well. Since the diameters of the drill pipe and of the well bore are known, and the depth of the well and length of the drilling string are known at all times during drilling, it is only a matter of simple calculation to determine the volume of fluid necessary to be pumped into the well in order to bring an increment thereof to the bottom of the well, and the additional volume to be introduced into the well in order to bring that increment back to the surface. Thus an increment of the drilling fluid together with any materials contained in, or comprising, that increment may be traced in its passage through the well and detected upon its return to the surface. Hayward Patent No. 2,214,674, issued September 10, 1940, contains a complete description of this method of tracing an increment of drilling fluid through a well during rotary drilling. Accordingly, by driving chart 25 by the volume of fluid flowing through meter 19, the movement of the chart for a distance corresponding to the passage of the calculated volume of fluid into the well will serve to indicate the exit from the well of the same increment which had entered the well at the beginning of the calculated volume. If the depth of the well, which is known at all times, is divided by the volume so found, a ratio is arrived at which may be expressed as, say feet per barrel, and which connects volume pumped with depth. Some cases, it has been found the actual figure does not always correspond with the theoretical because for one reason or another the bit may drill a hole somewhat larger or smaller than is expected. As the well is deepened from day to day, the volume of fluid required to pump the indicating medium around will increase but the ratio of feet per barrel will only vary very slightly from day to day. In such cases it is only necessary to make a suitable correction by circulating a "tell-tale" in the well-known manner to arrive at the exact volume of fluid in the well at any time.

A quantity of a suitable indicating medium, preferably of fluid character, adapted to give a characteristic self-identifying indication, is introduced through pipe 20 into the stream of drilling fluid entering the well through pipe 18. Its entry into the stream of drilling fluid will be indicated or noted in any suitable manner on chart 25. The indicating medium will travel through the well with the drilling fluid in which it will retain its position in the stream in the form of a slug or in relatively high concentration in the increment of the stream into which it is introduced. The confined character of the drilling fluid stream in its flow through the well makes possible the maintenance of this relatively stationary position of the medium in the stream, as is explained in detail in the aforementioned Hayward Patent No. 2,214,674. As the drilling fluid flows through the well and returns to the top thereof, a portion of the exiting fluid is continuously diverted from outlet pipe 13 through branch pipe 26 which passes the diverted portion of the stream through a detection apparatus of a form designed to be responsive to and thereby to detect, the presence of the indicating medium in the drilling fluid. Accordingly, when the increment of the drilling fluid containing the indicating medium passes through the detection apparatus, the latter will detect the indicating medium and transmit a suitable signal through connection 28 to pen arm 29 of the recorder. The latter will then make a suitable mark on chart 25 to denote the appearance of the indicating medium in the exiting drilling fluid. If there has been no leak or other opening in the drilling string above the bit openings, this mark will appear at that point on the chart which the chart will have attained corresponding to the passage into the well of the volume of drilling fluid necessary to move the indicating medium from its point of entry into the well to the point of exit from the well.

On the other hand, if a leak of any sort has occurred in the drilling string at any point above

the bit openings, when the increment of drilling fluid containing the indicating medium passes the point of the leak, a portion of this increment and its included indicating medium will be diverted from the main stream and forced through the leak by virtue of the existing differential pressures between the fluid columns inside and outside the drilling string, and will enter the rising column of drilling fluid in the annular space. This diverted portion of the indicating medium will thus be short-circuited in its flow through the well and will return to the surface earlier than the indications obtained on previous runs. Knowing the number of feet represented by a barrel of fluid pumped, a simple calculation will locate the point of leakage. A second indication will also appear on the chart at a point corresponding to a depth somewhat greater than the actual depth of the well. This is because owing to the leak, the rate of circulation down the drill pipe and up the hole below the leak will be somewhat less than normal. The appearance on the record of the return of the indicating medium earlier than expected will be an immediate warning of a leak in the drilling string and, therefore, of an incipient wash-out. By noting the extent of the movement of the chart between the point corresponding to the entry of the indicating medium into the well and the point corresponding to its emergence from the well, the volume of fluid represented by this movement of the chart can be readily ascertained. A simple proportional calculation will immediately apprise the operator of the depth, measured along the drilling string, at which the leak is present. For example, if the volume of drilling fluid required to displace the indicating medium entirely through its normal circuit through the well is pre-determined to be 500 barrels, and detection of the returning indicating medium occurs after only 200 barrels of drilling fluid has entered the well following the introduction of the indicating medium, the operator is immediately advised that a leak is present about two-fifths of the distance down the drilling string. Since the length of the drilling string is known at all times and is, in this example, say 5000 feet long, the operator will know from his simple calculations that the leak must be at a depth of about 2000 feet. When the drilling string is, thereupon, withdrawn from the well to replace the leak-containing section, the examination of the drilling string can be confined to the section which was at the indicated depth and much time, trouble and consequent expense will thereby be avoided.

Furthermore, since the path of flow of the drilling fluid through the well, including the drilling string and the annular space, is a continuous path of restricted cross-sectional area, the measurement of the drilling fluid may be made on the exiting fluid equally as well as on the entering fluid. In this case meter **19** may be placed on outlet pipe **13**, and a suitable mark made on chart **25** at the instant the indicating medium is introduced into the entering stream of drilling fluid. As long as the drilling fluid circulation is maintained, it will be obvious that the volume leaving the well will at all times equal the volume entering the well and vice-versa. Therefore, it becomes only a matter of practical consideration and convenience to decide at what point along the drilling fluid circuit, the measurements should be conducted.

The form of indicating medium employed is

preferably one which is of relatively short-lived or evanescent character such that, after it has completed one trip through the well and has been discharged from the well, it will disappear or become so distributed or dispersed in the main body of drilling fluid in the mud pits before return of the drilling fluid to the well that it will lose the distinguishing characteristic employed for its detection. Numerous materials of such character are available and may be used for the purposes of this invention. For example, gasoline or other volatile fluids which will vaporize readily at atmospheric or lower pressures are particularly useful for this purpose. As one example, a quart or less of low end point gasoline such as casing head gasoline, may be introduced into the drilling fluid stream. This body of liquid will, as noted, retain its position in the drilling fluid stream more or less as a single slug or highly concentrated in a relatively short increment of the drilling fluid stream and, under the relatively high pressures of the stream such a volatile fluid will not vaporize during its passage through the well. Even if vaporized to some degree, the vapors will, nevertheless, remain in the fluid increment in which gasoline was originally introduced. When, however, the gasoline is discharged at the top of the well at substantially atmospheric pressure, vaporization will take place. By making detector **27** a conventional type of gas detector, of the form described in the application of J. T. Hayward, Serial No. 265,470, filed April 1, 1939, now Patent No. 2,489,180, which normally applies a small degree of vacuum to the drilling fluid sample containing the gasoline, the presence of the resulting hydrocarbon vapors may be very readily and accurately detected. Thereafter, by the time the increment of the drilling fluid containing any small residual traces of gasoline has flowed through the usual mud ditches, shale shakers and mud pits prior to its return to the well, such traces will have become so widely and uniformly distributed that the drilling fluid, in its subsequent cycles through the well, will, at most, give only a relatively minor and relatively uniform indication of gas in the detector for all increments thereof passing through the detector, as contrasted with the indication of relatively large magnitude obtained from the increment containing the relatively large initial concentrations of the gasoline indicating medium, whether that increment be the one into which the gasoline was initially introduced or that which receives the portion diverted through a leak.

In the latter connection, it should be further noted that since the indicating medium is present in the drilling fluid stream as a relatively concentrated body or slug, diversion thereof through a leak in the drill pipe will continue only for so long as is required for the slug to pass the point of the leak. Once the slug has passed the point of the leak, no more of the indicating medium will be diverted to the fluid in the annular space with the result that the indication obtained by the detector at the surface will be relatively sharp in character and of short duration. The same is true of the indication obtained from the slug after it has passed through the bit openings and returned to the surface. Consequently, the record, such as that obtained on chart **25**, will have the appearance of the curve illustrated in Fig. 3 where no leak or incipient wash-out is present, and of that illustrated in Fig. 4, when a leak is present. It will be evident that if more

than one leak is present in the drilling string, some of the indicating medium will discharge into the fluid in the annular space as the medium passes each such leak and a series of indications corresponding to each of such leaks will appear on the record of the indications. Their respective positions will be determined in the manner previously described.

Other types of indicating mediums having the characteristics described are various types of combustible and non-combustible liquids and liquefied gases, dyes and short-lived radio-active materials. In the case of the combustible liquids or liquefied gases, the conventional combustible gas detectors of the hot-filament type may be employed for their detection. In the case of volatile non-combustible liquids, such as carbon tetrachloride or Freon, conventional convection type gas detectors which depend upon cooling of a heated filament, rather than heating by combustion, may be employed. Dyes may be detected by suitable color-responsive detectors. Fluorescent or phosphorescent indicating mediums may also be employed along with conventional detectors responsive to the characteristic fluorescence or phosphorescence of these materials. Artificially radio-active materials, having short radio-active lives corresponding to the time necessary to complete a trip through the well, may be employed with suitable radiation detectors such as Geiger-Muller counters or ionization chambers. In every case the indicating material preferably should have the quality of substantially losing its characteristics identifying property after the completion of a single trip through the well.

The method in accordance with this invention may be performed as frequently as desired during the drilling operation although in practice the test for incipient wash-outs will probably be made only once a day or once per shift. It will also be evident that the method in accordance with this invention may be performed without any interruption in the normal drilling operations.

Fig. 2 illustrates more or less diagrammatically and in somewhat greater detail a particular embodiment of apparatus which may be employed in accordance with the method of this invention for detecting wash-outs using volatile gasoline, of the type previously described, as the indicating medium, a hot wire gas detector as the detecting device and the mud pump itself as the metering device for metering the flow of mud fluid through the well. This apparatus comprises the conventional type of direct acting steam driven mud pump, indicated generally by the numeral **30**, having a fluid end **3** and a steam end **32** provided with the usual piston rod **33** connecting the steam piston to the fluid piston in the usual manner. Piston **33** carries a crosshead **34** which drives the usual rocker arm **35** conventionally employed to operate the pump valve mechanism (this connection not being shown). The upper end of rocker arm **35** is pivoted in the conventional manner at **36** on a supporting bracket **37** mounted on the pump structure. The upper end of rocker arm **35** carries one contact **38** of an electrical switch adapted to close with the other contact **39** of the switch at least once during each pump cycle. Contacts **38** and **39** are connected through electrical leads **40** and **41** respectively, into which is inserted a suitable current source **42**, to the drive chart **25** of recorder **24**. The fluid-end discharge of pump **30** is connected into pipe **18** having branch pipe **20** and valve **21** connected thereto as in the previously described embodiment. Drilling fluid coming from the suction pit (not shown) is drawn into the fluid end of the pump through pipe **43**. With this arrangement, pump **30** may be employed as a meter for the drilling fluid being pumped thereby to the well. The electrical impulses produced by the making and breaking of the rocker arm switch in response to the movements of rocker arm **35** are employed to drive the chart, which may be calibrated in terms of pump cycles. In other words, the chart will be moved a pre-determined distance per pump cycle or for a suitable number of pump cycles. The volume of drilling fluid discharge per cycle of the pump may be readily calculated for positive displacement pumps of the type here described and suitable correlation may be made therefrom with the number of pump cycles required to move the drilling fluid through the well or per unit length in the drill string and the well. The aforementioned Hayward Patent No. 2,290,179 discloses such an apparatus arrangement suitable for counting the cycles of a direct-acting pump.

Branch pipe **26**, which may be the same as that described in the previously described embodiment, is shown connected into a gas trap **44** of any suitable or conventional construction which will assist in the continuous release of gas from the drilling fluid flowing therethrough. An air inlet **45** is connected into the upper portion of the trap for supplying combustion-supporting air to the gas released in the trap. A vapor pipe **46** leads from the upper end of trap **44** to a gas detector **47** of the conventional hot-filament type and a suction pump **48** is connected to the downstream side of the gas detector for drawing vapors from gas trap **44** through pipe **46** into and through the gas detector. Vacuum pump **48** will, at the same time, be employed to create a small vacuum in the gas trap to aid in the release of gas from the drilling fluid and to draw air through inlet **45** into the trap. A valved pipe **49** is connected into the connection between the gas detector and pump **48** for regulating the degree of vacuum maintained by pump **48**. The measurements of the gas concentrations in the vapors going to gas detector **47** are converted therein in the usual manner to electrical quantities which are transmitted through leads **48—49** to recorder **24** for driving its pen arm **29**. This apparatus is employed for detecting incipient wash-outs in the following manner:

A pint or so of volatile gasoline will be introduced through pipe **20** into pipe **18** and a suitable mark, indicated at **50**, will be made on chart **25** to note thereon the introduction of the indicating fluid into the stream of drilling fluid. When the increment of the drilling fluid containing the gasoline returns from the well and a portion thereof passes through gas trap **44**, an indication thereof will be transmitted by the gas detector to chart **25** and will appear thereon in the form of a peak **51** in the curve of the gas record being continuously plotted relative to pump cycles on the chart by pen arm **29**. If peak **51** appears on the chart a number of pump cycles after point **50** which corresponds to the expected number of pump cycles necessary to displace the slug of gasoline entirely through the well, it will be immediately apparent to the operators that no wash-out or incipient wash-out is present in the drilling string. If, however,

a peak **52**, indicating a relatively high gas reading, appears on the chart prior to the point at which peak **51** subsequently appears or is anticipated, the operators will be immediately apprised that there is a leak somewhere in the drilling string. By reading from the chart the number of pump cycles between the initial point **50** and peak **52** the operators can readily calculate the position of the leak along the drilling string. As indicated, the very appearance of an intervening peak in the gas record will be an immediate warning of an incipient wash-out.

Chart **3** illustrates the form of gas chart, such as that obtained by this embodiment in which one ordinate of the curve is in terms of pump cycles and the other ordinate in terms of percent of gas in the vapors passing through the gas detector. In this illustration, one thousand pump cycles is taken to represent a volume of drilling fluid found necessary to be pumped into the well to displace the gasoline entirely through the well. Curve **53** corresponds to the gas record being continuously made by the detector on the chart and it will be seen that the gas percentage remains relatively unchanged until a point corresponding to a thousand pump cycles is attained, at which point peak **51** appears, thereby indicating that the gasoline has passed through the entire well and returned to the surface after the pre-determined number of pump cycles.

Fig. 4 illustrates a similar chart in which peak **52** appears after 500 pump cycles, followed by the appearance of peak **51** after something more than 1000 pump cycles. This record will indicate, therefore, that there is a leak in the drilling string at a point corresponding to 500 pump cycles, which will immediately indicate that there is a leak approximately half-way down the drilling string. Since the length of the drilling string is known to the operators, it is obvious that the operators will be able to find the leak very readily as the drilling string is withdrawn from the well and the previous difficulties in finding such a leak will be greatly reduced.

It will be understood that various changes and alterations may be made in the details of the method and apparatus herein disclosed without departing from the scope of the appended claims but within the spirit of this invention.

What I claim and desire to secure by Letters Patent is:

1. In the method of drilling wells wherein a hydraulic fluid is circulated into and out of a well through a hollow drilling string, the method of detecting and locating leaks in said drilling string, comprising, introducing a readily identifiable indicating medium into an increment of the stream of drilling fluid as it enters the well, advancing a record chart in accordance with the volumetric flow of said drilling fluid displacing said increment through the well, detecting said medium in the fluid emerging from the well, and recording on said chart in correlated relation to the respective volumes of drilling fluid emerging from the well indications of said medium as detected both in said increment and in any earlier emerging increment of said drilling fluid to thereby disclose from the difference in positional relationship on said chart of said indications the existence and location of a leak in said drilling string.

2. In the method of drilling wells wherein a hydraulic fluid is circulated into and out of a well through a hollow drilling string, the method of detecting and locating leaks in said drilling string, comprising, introducing a readily identifiable vaporizable liquid medium into an increment of the stream of drilling fluid as it enters the well, advancing a record chart in accordance with the volumetric flow of said drilling fluid displacing said increment through the well, continuously detecting vapors of said medium evolving from the drilling fluid emerging from the well, and continuously recording on said chart in correlated relation to the respective volumes of drilling fluid emerging from said well indications of said vapors evolving both from said increment and from any earlier emerging increment of said drilling fluid to thereby disclose by the difference in positional relationship on said chart of said indications the existence and location of a leak in said drilling string.

JOHN T. HAYWARD.

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