Sept. 7, 1943. H. HOOVER, JR 2,328,555

WELL LOGGING METHOD

Filed May 27, 1940

Fig-1-

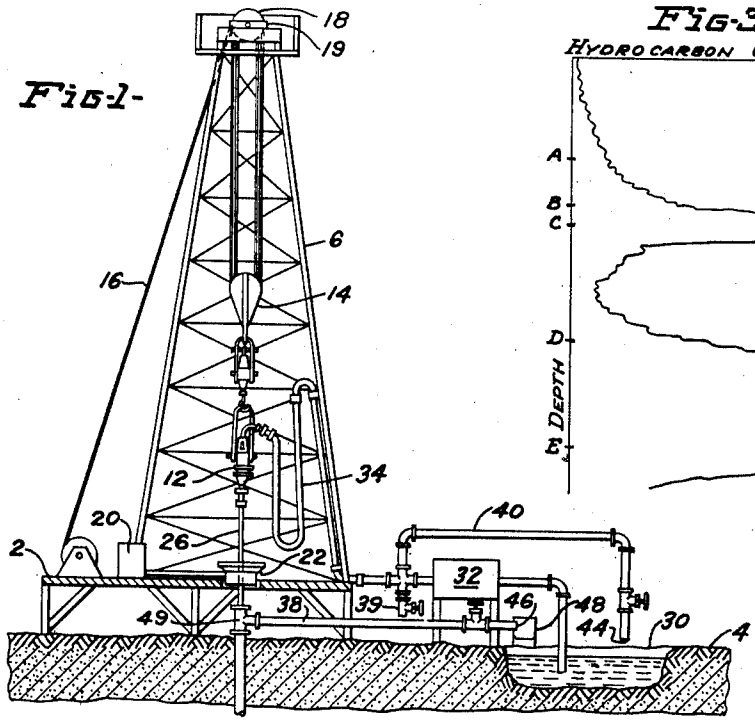


Fig-3-

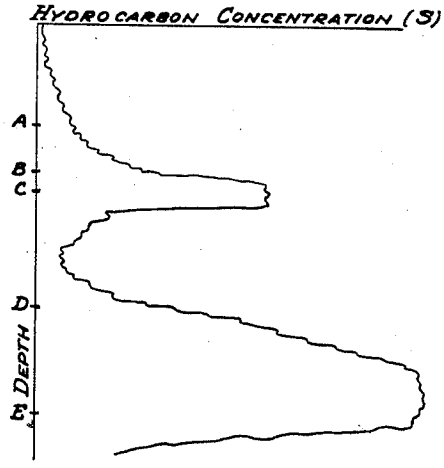


Fig-2-

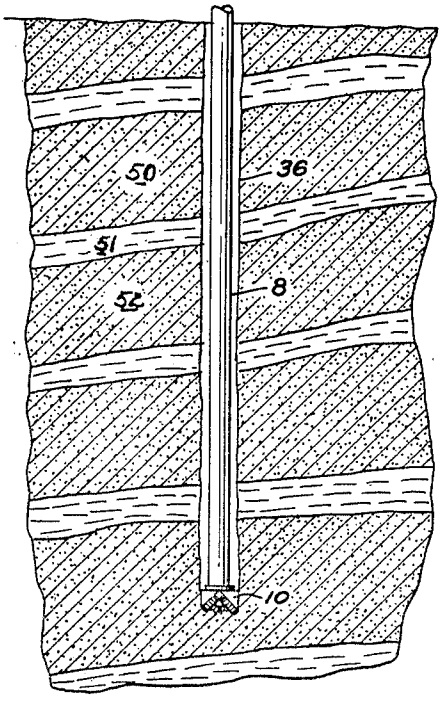
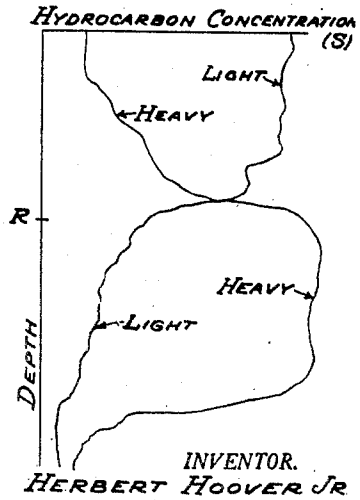


Fig-4-



INVENTOR.
HERBERT HOOVER JR
BY Reed & Lawlor
AGENT.

Patented Sept. 7, 1943

2,328,555

UNITED STATES PATENT OFFICE

2,328,555

WELL LOGGING METHOD

Herbert Hoover, Jr., Sierra Madre, Calif., assignor to Consolidated Engineering Corporation, Pasadena, Calif., a corporation of California

Application May 27, 1940, Serial No. 337,503

2 Claims. (Cl. 255—1.4)

This invention relates to a method for logging the formations of an oil well during the course of drilling and in particular to a well logging method in which measurements are made of the concentration of hydrocarbons occurring in the formations encountered as drilling progresses.

According to my invention I analyze drilling mud for hydrocarbon content during the course of drilling, and in this way determine the amount of hydrocarbons present in the drilling mud as a result of contact with subterranean strata. In order to obtain a hydrocarbon well log which is accurate, I obtain samples of drilling mud prior to passage down the drill pipe to the point at which the drilling is taking place and later obtain a corresponding sample of drilling mud that returns to the surface after making a single complete cycle. By analyzing the two samples, which will hereinafter be referred to respectively as the "in" and "out" samples, for their respective hydrocarbon contents, I am able to measure the net change in hydrocarbons produced in the drilling mud as a result of contact with the subsurface.

Occasionally the net change of drilling mud hydrocarbon concentration is a decrease caused for instance from an influx of connate waters into the drilling mud. However, when operating in accordance with the preferred form of my invention the net change is an increase representing both the hydrocarbons which have dissolved in the drilling mud and those retained in the drill cuttings.

The measured quantities of hydrocarbons may be representative of hydrocarbons which have migrated upward from a deep deposit underlying the stratum from which the cuttings originate, or they may signify a concentrated petroleum deposit which may have commercial value. The distinction between the two possible interpretations to be given to the data obtained, depends partly on whether an increase in hydrocarbon concentration with depth is observed and partly on the total quantity of hydrocarbon observed.

As is well known, it is often necessary to make an electrical survey of a well subsequent to the completion of drilling in order to ascertain whether an oil sand has been overlooked. In case large quantities of hydrocarbons of possible commercial importance exist in the stratum being penetrated by the drill, the existence of such large quantities may be detected according to my invention at the surface during the course of drilling without any danger of being overlooked because of being sealed off by the mud cake accumulating on the bore hole wall.

Small quantities of hydrocarbons returned with the drilling mud, increasing in concentration with depth indicate the approach of the drill to a productive horizon. In case the hydrocarbons from the drill mud are hydrocarbons which have migrated from deep lying deposits, the existence of such deposits may therefore be detected prior to the penetration thereof by the drill.

My invention is also useful in detecting the nature of the deposits existing in the strata penetrated by the drill. In this way I can determine whether a petroleum deposit encountered has the gravity or other characteristic suitable for commercial purposes.

By determining the relative proporitons of heavy and light hydrocarbons returned with the drilling mud during the course of drilling I am able to locate the surface of separation between the gas and oil bearing levels in a petroleum bearing stratum. Thus, I can also locate the gas-oil interface in a productive zone and aid a driller in setting casing at the optimum position in the well prior to a production test.

Accordingly, the principal object of my invention is to provide a method of exploring for valuable subterranean mineral deposits.

Another object is to provide a method for logging a well during the course of drilling which will detect directly hydrocarbons present in the formations encountered by the drill.

Another object is to provide for obtaining a hydrocarbon well log free from any error arising from contaminating hydrocarbons present in the drilling mud prior to pumping said mud into the well.

Another object is to provide for determining the constituency of a petroleum deposit encountered in the course of drilling.

Another object is to provide a method of detecting the presence of a producing stratum prior to its penetration by a drill.

Another object is to provide a method for detecting the gas-oil interface in a productive zone.

My invention possesses numerous other objects and features of advantage, some of which, together with the foregoing, will be set forth in the following description of specific apparatus embodying and utilizing my novel method. It is therefore to be understood that my method is applicable to other apparatus, and that I do not limit myself, in any way, to the apparatus of the present application, as I may adopt various other

apparatus embodiments, utilizing the method, within the scope of the appended claims.

In the drawing:

Fig. 1, which is partly schematic and partly in section, shows a typical organization of surface drilling equipment to which my invention is applicable.

Fig. 2 drawn to a larger scale than Fig. 1 shows a section of the earth near the bottom of a drill stem.

Figs. 3 and 4 represent well logs obtained in accordance with my invention.

Referring to Figs. 1 and 2, a platform 2 mounted on the surface 4 of the earth has constructed thereon a derrick 6 which is used to support and manipulate a drill pipe 8 having a bit 10 on the bottom end thereof for drilling into subsurface formations. The drill pipe is connected at its uppermost end to a swivel 12 which in turn is supported by a travelling block 14. The drill pipe may be raised or lowered vertically by taking up or letting out the drill cable 16 which passes several times over the pulley 18, on crown block 19 and a pulley on a travelling block 14. The pressure of the drill on the bottom of the drill hole is controlled by manipulation of the tension in cable 16.

Rotary motion is supplied to the drill pipe 8 and bit 10 by suitable transmission of energy from a motor 20 to a rotary table 22 mounted on platform 2, said rotary table being adapted to transmit motion to the drill pipe 8 through a kelly 26 which forms the uppermost section of said drill pipe 8.

In order to lubricate the drill bit 10 during drilling and to remove drill cuttings from the drill hole, mud of predetermined constituency is pumped from the sump 30 by a pump 32 through the hose 34, and swivel 12 into a continuous passage which extends throughout the entire length of the drill pipe from kelly 26 to bit 10. When the mud reaches the drill bit it passes into the drill hole and picks up any drill cuttings which may be present. The mud laden with cuttings is returned to the surface through the space between the wall 36 of the drill hole and the drill pipe.

It is clear that in general some of the hydrocarbons which may be present in the formation through which the drill is passing, dissolve in the mud and some are retained by the cuttings.

When the mud returns to the surface it is discharged into the sump through a discharge pipe 38. Due to the fact that any hydrocarbons picked up by the mud in the course of drilling thus enter the sump and increase the average hydrocarbon content of the mud entering the drill pipe and the fact that light hydrocarbon constituents present in the sump continually evaporate, the hydrocarbon content of mud entering the drill pipe is in a continually changing state.

According to my invention I obtain an accurate measure of hydrocarbon content of the formations encountered by the drill during the progress of drilling by comparing the hydrocarbon concentration of the mud when it returns to the surface with the hydrocarbon concentration the same mud had when it was introduced into the drill pipe. Preferably, I measure the total concentration of hydrocarbons in the returned drill mud including both hydrocarbons which become dissolved in the drill mud and hydrocarbons retained by the cuttings.

I may obtain an "in" sample at any desired time by collecting a portion of the drilling mud from the mud faucet 39 or from the end of bleeder line 40 in a pan or jar held beneath said faucet 39 or the end 44 of bleeder line 40. The "in" sample is preferably taken while the drilling equipment is operating in a steady, stable condition. In taking an "in" sample, any mud standing between the mud line and the point of collection is first drawn off so that the "in" sample is representative of the drilling mud passing into the drill pipe at the time said "in" sample is collected.

Another, but less satisfactory way, of obtaining an "in" sample, is to collect mud directly from the bottom of the kelly 26 or from the hose 34 at the time that an additional section of drill pipe is introduced to increase the drill pipe length for drilling deeper.

I obtain an "out" sample directly by collection of a portion of the drilling mud at the outlet 46 of the discharge line 38. Said "out" sample is preferably obtained at a point as close as possible to the drill collar 49 before any substantial amount of hydrocarbons have had a chance to be lost by evaporation. In case there is any considerable pressure on the return drill mud, I prefer to collect and maintain the sample at said pressure. In collecting the "out" sample I include both mud and cuttings contained therein in order to get a sample truly representative of the formation being drilled.

The mud cycle may be measured, for example, by introducing a marker, such as a handful of oats into the mud, just prior to pumping the mud into the drill pipe. The oats may be introduced into the drill pipe if desired when a new stand of drill pipe is added. The oats may later be detected in the return mud by any convenient method such as by passing the return mud through a screen 48 prior to return of the mud to the sump. A shaker screen which may be used for this purpose is usually available at the well.

The length of time required for the oats to pass through the drill pipe and return to the surface is known as the mud cycle.

To obtain a log of the formations encountered by the drill, I correlate the "in" and "out" samples together with the corresponding depth in a single mud cycle.

From the pumping rate and the length and cross-section of the drill pipe and drill hole, I can determine the position of any particular portion of mud in the drill system at any time after taking an "in" sample. Accordingly, I can compute the length of time required for mud to pass from the pump 32 down to the formation being drilled. Thus, I may readily determine the time and the corresponding depth at which the mass of mud corresponding to any given "in" sample will pick up cuttings at the bottom of the drill hole and when this mud sample will return to the surface with said drill cuttings and any hydrocarbons contained in the portion of formation being drilled away.

In the preferred form of my invention, the formations previously passed through by the drill such as strata 50, 51, and 52 above the drilling point cannot make any substantial contribution to the hydrocarbon content of the returning drill mud, first by virtue of the fact that a mud cake is usually formed on the wall 36 of the drill hole effectively sealing off the formations and secondly, by virtue of the fact that I maintain the density of the drilling mud high enough for the

hydrostatic head of the drilling mud to exceed any formation pressure which I expect to encounter. Thus, the increase in hydrocarbon content of any portion of mud under examination is representative of the formation being penetrated by the drill. In order to measure the concentration of hydrocarbons in the formation being drilled I compare the increase in hydrocarbon content of the mud with the amount of formation drilled through during the passage of a standard quantity of mud.

Since the volume of subsurface stratum penetrated during the course of drilling is usually very small compared with the amount of mud passing the drilling point, the concentration of hydrocarbons per unit volume of formation may usually be expressed by the equation

$$S=(H_0-H_i)\frac{M}{D}$$

where

H_0=hydrocarbon concentration in "out" sample
H_i=hydrocarbon concentration of "in" sample
M=mud rate, i. e., volume of mud flowing past any point in the drilling system per unit time
D=drilling rate, i. e., volume of formation being removed by the drill per unit time.

The mud rate (M) may be measured in any convenient manner, such as, by determining the length of time required for mud to fill a container of measured volume at the outlet **46**.

The drilling rate (D) may be determined readily from the diameter of the hole being drilled and the rate at which the drill is penetrating the formation.

In order to determine the hydrocarbon concentrations H_0 and H_i, corresponding respectively, to the "out" and "in" drilling mud samples, I collect these samples in any convenient manner such as that hereinabove described, place the samples in airtight containers, make records of the depths to which said samples correspond, record the mud and drilling rates and transport said samples to a central laboratory where the hydrocarbon concentrations of the samples may be measured by any convenient method either chemical or physical.

I prefer to use a mass spectrometer for my analysis of the "in" and "out" samples, since with this instrument I may obtain a complete analysis of the various hydrocarbon constituents of the drilling mud and thereby provide data for determining the nature of the hydrocarbons which are contained in the strata under investigation. By making a complete analysis I am thus able to determine whether any petroleum deposit encountered possesses commercially desirable qualities.

In Fig. 3 I have shown a typical graph of total formation hydrocarbon concentrations (S) obtained by my method. Down to the depth A it is seen that only small concentrations of hydrocarbons gradually increasing with depth are present, but beginning from the depth A to the depth B the hydrocarbon concentration rapidly increases indicating the approach of the drill to a productive horizon, while at depth C the total quantity of hydrocarbons found indicates that a saturated oil sand exists at this level. Similarly, the gradual increase of hydrocarbon concentration, in the region of point D indicates the approach of an oil sand located at the depth E.

If desired, separate logs may be made of individual hydrocarbon constituents detected. In Fig. 4 I have shown on an enlarged depth scale a plot of the concentrations of both heavy and light hydrocarbons found in a productive zone. For my purpose hydrocarbons heavier than butane are considered "heavy" while butane and lighter hydrocarbons may be considered "light." The division into light and heavy is more or less arbitrary and may be varied according to the requirements of the area. For the purpose of locating a gas-oil interface, samples are preferably taken at closely spaced points, preferably less than two feet apart. By an examination of a heavy-light hydrocarbon log a driller is enabled to set casing at such a point that a good production rate may be obtained without excessive loss of formation energy. The bottom of the casing is preferably set a short distance below the least depth R where the heavy hydrocarbon concentration reaches a high value. A water-oil interface may also be detected in accordance with my method.

It frequently happens that certain strata which persist throughout a large area contain characteristic concentrations of hydrocarbons which are of no commercial value. While my invention is primarily useful in detecting a productive horizon either directly or by the approach of a drill to a productive horizon, it may also be used to correlate the depths at which such characteristic marker beds appear in different holes drilled in an area under investigation.

In case an abnormally large concentration of any particular hydrocarbon is found in any stratum in excess of the concentration characteristic of such stratum, it is usually indicative of a substantial deposit of petroleum within or near such stratum.

In general my invention provides a method of hydrocarbon well-logging in which correction is made for the previous history of the drill mud, by comparing the hydrocarbon concentrations of two mud samples, one taken at the beginning and one at the end of a common mud circulation cycle. The concentration of hydrocarbons in the formation being penetrated by the drill is computed by taking into account the rate at which the drill is penetrating the formation under test and the rate at which mud is circulating through the drilling system.

While I prefer to maintain the mud pressure substantially higher than the pressures in any formation encountered in order to avoid substantial diffusion or flow of hydrocarbons into the drilling mud, it is clear that my invention will also be applicable even when the mud pressure falls below the pressure in a formation already penetrated by the drill. The effect of such a lowering in pressure will be merely to produce a substantially constant hydrocarbon concentration background as a result of continual influx of hydrocarbons from such a formation into the mud. The magnitude of such a background varies directly as a function of the difference in mud and formation pressures and also inversely as a function of the length of the mud cycle.

Many variations may, of course, be made in my method within the spirit of my invention, and the scope of the appended claims. For example, the concentration of hydrocarbons may be expressed in terms of the weight of the subsurface formation instead of the volume, or the volume of cuttings returned to the surface may be measured directly if desired and the significant concentration of hydrocarbons expressed in terms of the volume of the cuttings returning in

a unit length of time instead of computing the volume of formation being penetrated from the size of the drill hole and the rate of penetration.

It is sometimes desirable to maintain the mud in the sump substantially homogeneous by continual mixing thus making it unnecessary to collect an "in" sample for every "out" sample. This is especially useful when "out" samples are obtained in rapid succession.

While I prefer to analyze the total contents of "in" and "out" drilling mud, I also recognize the fact that under many conditions the gases present in the mud water will reach an equilibrium condition with respect to the gases present in the solid particles suspended in the mud. Accordingly, under such conditions the hydrocarbon content of the drilling mud water will be a measure of the total quantity of hydrocarbon present in the mud.

In one form of my invention I therefore extract water samples at the inlet and outlet ends of the drilling system and compare their hydrocarbon contents for detecting petroleum bearing deposits. Such water samples may be obtained, for instance, by screening out the cuttings and precipitating or filtering out suspended matter.

It is to be understood that my invention is also applicable to the detection of subsurface mineral deposits other than petroleum.

I claim:

1. In a well drilling operation, the improvement which comprises locating a gas-oil contact in a petroleum bearing zone by determining the increments of light hydrocarbons and the increments of heavy hydrocarbons in a series of portions of the mud column circulated past the bottom of the well, said portions being substantially undiluted by infiltration of fluids from said zone but containing cuttings corresponding to successive bottom points in said zone at known depths in the well, some of said points being above and some below the gas-oil contact, and determining the depth in said zone at which the increment of heavy hydrocarbons increases rapidly as compared with the increment of the light hydrocarbons.

2. In exploring a petroleum bearing zone having a gas-oil contact therein during a well drilling operation in which cuttings are carried out of the well by a column of mud circulated between the top and the bottom of the well during the drilling thereof in said zone, the improvement which comprises simultaneously logging the well by taking two series of samples respectively from a series of portions of the mud column, samples of one series being taken before and samples of the other series being taken after the respective portions of the mud column have accumulated cuttings from a series of bottom points in said zone and at known depths, some of said bottom points being above and some below the gas-oil contact, maintaining the density of the mud column so high that the hydrostatic head exerted by the mud column in the well is in excess of the formation pressure exerted by the fluids in said zone thereby preventing inflow into the mud of fluids from said zone, measuring the amount of light hydrocarbons and the amount of heavy hydrocarbons in each of the samples of both series, and determining from the resulting measurements the proportion of the increment of light hydrocarbons and the increment of heavy hydrocarbons in each of the portions of the mud column corresponding to the series of bottom points, whereby the depth of said gas-oil contact may be determined.

HERBERT HOOVER, JR.