

[54] METHOD AND APPARATUS FOR DETECTING AN INFLOW OF FLUID INTO A WELL

3,305,825 2/1967 Godbey..... 73/151 X

[75] Inventor: Charles B. Vogel, Houston, Tex.

Primary Examiner—Jerry W. Myracle  
Attorney—Theodore E. Bieber et al.

[73] Assignee: Shell Oil Company, Houston, Tex.

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[57] ABSTRACT

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A method and apparatus for detecting an inflow of fluid into a well during rotary drilling of the well wherein an inflow of gas is detected by acoustic means and an inflow of water is detected by resistivity means, the resulting information being transmitted to the surface by means of pressure pulses produced in the drilling fluid circulated during drilling.

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13 Claims, 2 Drawing Figures

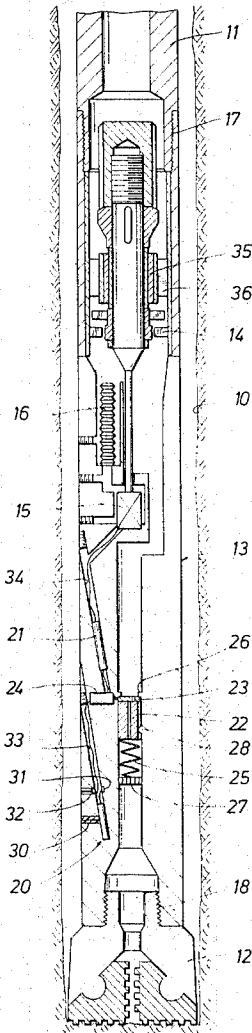
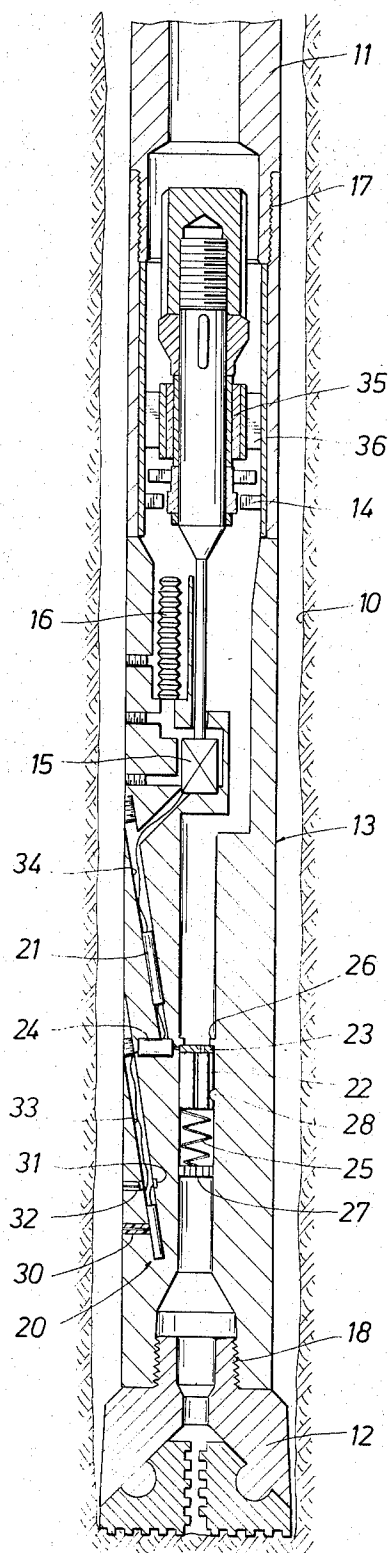


FIG. 1



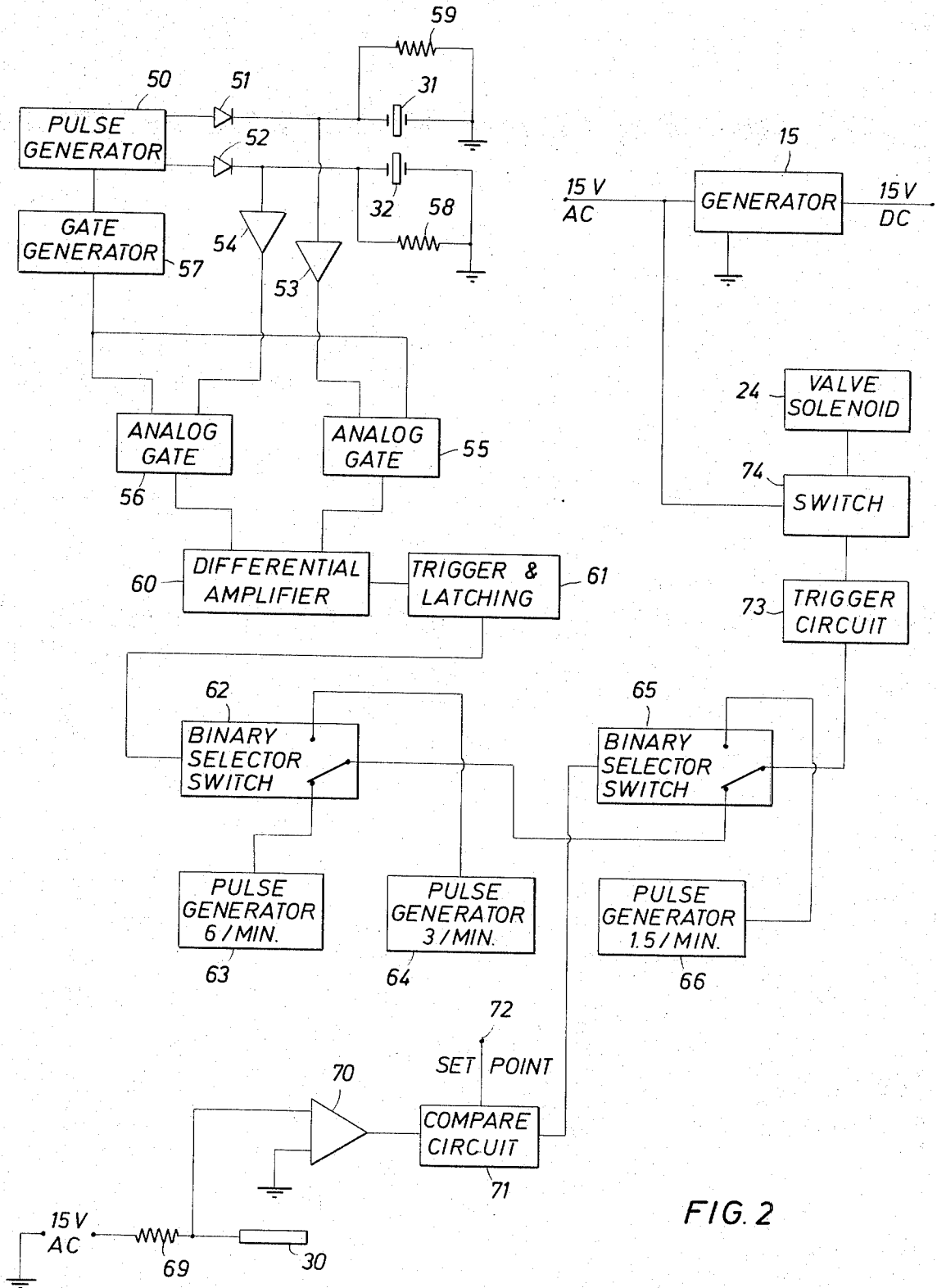


FIG. 2

## METHOD AND APPARATUS FOR DETECTING AN INFLOW OF FLUID INTO A WELL

### BACKGROUND OF THE INVENTION

The present invention relates to a method and apparatus for detecting an inflow of either gas or liquid into a well during the drilling of the well. The invention is particularly adapted for use with rotary drilling equipment. In the rotary drilling operation a drill bit is attached to the end of a tubular drill string and extends into the well. The drill string is rotated by surface equipment while liquid, commonly referred to as drilling mud, is circulated through the tubular string, out of the drill bit and returns to the surface through the annulus between the drill string and the borehole wall. The drilling mud is circulated both to cool the drill bit and bring the drill bit cuttings to the surface.

One of the problems that is encountered in the rotary drilling of wells is blowouts of underground formations as they are penetrated by the drill bits. A blowout normally occurs when the formation pressure exceeds the hydrostatic head generated by the column of drilling mud in the borehole. The hydrostatic head of the drilling mud can be seriously reduced by the gradual inflow of either gas or liquids, particularly salt water, into the well. As these fluids flow into the well they reduce the specific gravity of the drilling fluid which is normally measured in pounds per gallon and referred to as ppg. A point is reached where the specific gravity of the drilling fluid has been reduced to a value where the hydrostatic head of the drilling mud is no longer sufficient to restrain the formation pressures. When this point is reached, the well blows out at the surface. At times, of course, it is possible to take various measures to control the blowout, while at other times serious accidents have occurred.

In the past it has been suggested that various methods may be used for transmitting information from the bottom of the borehole to the surface during the actual drilling of the well. Two of the methods suggested for transmitting information comprise an electrical circuit inserted in the drill string and the generation of pressure pulses in the mud stream. While these methods are known for transmitting information, no reliable method has been devised for detecting the inflow of fluids into the well. It is obvious that if it were possible to detect the inflow of fluids into the well and transmit the information to the surface, the conditions that lead to blowouts could be corrected before they become serious.

### BRIEF SUMMARY OF THE INVENTION

The present invention solves the above problems by providing unique method and apparatus for sensing the inflow of fluids into the well. More particularly, the method and apparatus will sense the inflow of either gas or liquids into the well bore during the actual drilling of the well. The exact apparatus described is particularly adapted for use with a transmission system using pressure mud pulses to transmit the information, although it could be modified for use with an electrical transmission circuit.

The apparatus comprises a pair of acoustical transducers which are energized at a relatively high frequency. One of the transducers is disposed to transmit pressure waves through the drilling mud before it is circulated to the drill bit. The second transducer is disposed to transmit pressure waves through the drilling

mud after it is circulated through the drill bit and is returning to the surface through the annular space between the drill string and the borehole. The transducers generate signals that are related to the received scattered and reflected acoustical energy, the signals compared, and the difference between the signals transmitted to the surface. When there is no inflow of gas into the well, the signals from the two transducers will be substantially equal and no difference in signal will occur. It has been discovered that only a small quantity of gas, for example 1 percent by volume, will cause a distinct difference in the two transducer signals. This difference can then be converted to a signal which is transmitted to the surface by means of mud pulses.

Also included in the apparatus is an electrode for measuring the resistivity of the drilling mud. The resistivity of the drilling mud will remain relatively constant, unless there is an inflow of fluid into the well. The inflow of fluid can be either salt water or crude oil.

The signal transmitting system comprises three separate pulse generating circuits having different frequencies. Thus it is possible to select a frequency indicating no inflow of fluids into the well; a second frequency indicating the inflow of gas into the well; and the third frequency to indicate the inflow of liquids, either crude oil or salt water, into the well. Of course, the apparatus could be extended so that it is possible to include information indicating that both gas and liquids are flowing into the well. Normally, this is not required since the information that there is an inflow into the well is sufficient to alert the drilling personnel that steps must be taken to control the well before a serious blowout occurs.

### BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be more easily understood from the following detailed description of a preferred embodiment when taken in conjunction with the attached drawings in which:

FIG. 1 is an elevation view of a drill string in a well incorporating apparatus of the present invention, and FIG. 2 is a schematic circuit of the apparatus shown in block diagram form.

### PREFERRED EMBODIMENT

Referring now to FIG. 1, there is shown the present invention installed in the drill string disposed in a borehole 10. More particularly, the invention is installed in an instrument sub 13 which is attached to the drill string 11 at its upper end and has a rotary drill bit 12 disposed at its lower end. As is customary in rotary drilling practices, drilling mud or fluid is circulated down the center of the drill string or stem 10 through the passageway formed in the instrument sub and out the center of the rotary bit 12. The drilling mud then returns to the surface through the annular space between the outer surface of the drill string and instrument sub and wall of the borehole 10. The drilling mud serves both to cool and lubricate the drill bit 12, as well as to carry the drill cuttings back to the surface.

In addition, the drilling mud is weighted with various materials so that the hydrostatic head generated by the column of drilling mud in the borehole is sufficient to hold back the anticipated pressures of the formations penetrated by the borehole.

Mounted in the upper portion of the instrument sub is a mud turbine 14 which drives a generator 15. The

generator generates the power required by the various electronic circuits and operates various portions of the instrument. A bellows-type pressure compensating-equalization system 16 is provided so that the pressure within the generator is maintained slightly above the pressure in the mud system so that any leakage will be from the generator out instead of from the mud system into the generator. The circuits required for powering the resistivity logging portion of the system are disposed in an instrument package 20 which is mounted in a passageway 33 formed in the wall of the instrument sub. The instrument package 21 used for powering and controlling the acoustical transducers 32 and 31 is mounted in a similar passageway 34 disposed above the passageway 33. The electrode 31 of the resistivity sensor is disposed in a horizontal passageway which intersects the passageway 33. Similarly, the acoustic transducers 31 and 32 are disposed in the horizontal passageway which also intersects the passageway 33. A more detailed description of the electrode 30 and acoustic transducers 31 and 32 and their associated instrument packages is set forth below.

The data sensed by the resistivity and gas detectors is transmitted to the surface by means of pressure pulses produced in the circulating mud system. The pressure pulses are produced in the circulating mud system by means of a valve which effectively chokes the passageway through the center of the instrument sub. The valve comprises a piston 22 disposed for axial movement and having a central bore for passage of the mud stream and a valve 23 having a bore which may be either aligned with the bore in the 22 piston or to close the bore through the 22 piston. The valve 23 is positioned by means of a solenoid 24 which is actuated to produce a predetermined number of pulses in the mud stream to signify a certain condition. The piston is moved to an upper position by means of a compression spring 25 which forces the piston and valve assembly up against a stop 26 formed on the inner surface of the instrument sub. The compression spring 25 rests at its lower end against a horizontal plate 27 formed in the inner wall of the instrument sub. The plate 27 also has suitable openings so that the mud may flow through the openings. An inclined surface 28 is formed on the inner surface of the instrument sub and is used for resetting the valve 23. More particularly, the pulse system operates by the solenoid first moving the valve 23 to a position where it effectively chokes off the central bore through the piston 22. The circulating mud will then force the piston downwardly until the valve 23 strikes the inclined surface 28 which will force the valve to the left. This will again align the opening in the valve with the bore through the piston so that the mud may freely circulate. This will permit the spring 25 to return the piston to the upper position where the solenoid can again be actuated to produce another pressure pulse in the circulating mud stream. The frequency of the pressure pulses can be controlled to signify the condition being measured by the electrode 30 or the acoustic transducers 31 and 32.

To insure that the flow of drilling mud is not stopped completely in case of failure of the valve mechanism, suitable passageways are provided around the exterior of the piston 22 to provide a sufficient flow of drilling mud. For example, one could provide 25 percent of the area in the central passageway of the piston and the re-

maining 75 percent of the area in the passageways around the exterior of the piston.

Referring now to FIG. 2 there is shown in block diagram form the circuits required for operating the valve to generate the pressure pulses in response to the measurements made by the acoustic transducers and the resistance measuring electrode. A pulse generator 50 is coupled to the acoustic transducers 31 and 32 through diodes 51 and 52. Also coupled to the transducers are suitable inductances 58 and 59 designed to cause the transducers to resonate. The pulse generator 50 should generate a 5 volt pulse of approximately 5 MH. The two transducers are disposed so that the transducer 31 produces acoustic waves in the drilling mud circulating through the center of the instrument package sub while the transducer 32 produces acoustic waves in the drilling mud after it is passed through the drill bit and is returning to the surface through the annular space surrounding the drill string. Thus the transducer 31 produces a reference signal related to the drilling mud without fluid intrusion. In place of the reference transducer 31 one could also substitute a fixed signal. The two transducers are coupled to two analog gates 55 and 56 through the amplifiers 53 and 54, respectively. The two gates 55 and 56 are opened and armed by a gate resonator 57 which is also coupled to the pulse generator 50. The gate resonator 57 should produce a pulse for arming the two gates a certain delay period after the production of the pulse which energizes the acoustic transducers. For example, a pulse with a delay period of 7.5 microseconds and a width of approximately two microseconds will operate satisfactorily. Thus the two gates, 55 and 56, will transmit the acoustic signal that is reflected and scattered from the drilling mud back to the two transducers 31 and 32. This signal will be converted to a related electrical signal by the transducers which can be then amplified and passed through the gates.

The two gates are coupled to a differential amplifier 60 which produces an output signal related to the difference between the two transducer signals. In the absence of any inflow of fluid into the well, the two transducer signals will be substantially the same and thus the amplifier 60 will produce a zero output signal. Of course it may be necessary to adjust the amplitude of a signal received by one of the transducers to exactly balance the circuit. When a reference signal is used in place of reference transducer 31, that portion of the circuit associated with transducer 31 may be eliminated and the signal in the form of a voltage applied directly to the differential amplifier 60. The differential amplifier is coupled to a trigger and latching circuit 61 which triggers at a certain voltage level to provide an output signal having amplitude and duration sufficient to operate the binary selector switch 62. For example, a conventional Schmidt trigger circuit may be used for the circuit 61. Thus, whenever the differential amplifier 60 produces an output signal having sufficient amplitude, the trigger and latching circuit will be actuated and remain in an actuated state until the amplified signal falls below the triggering level of the circuit.

The system is provided with three pulse generators, 63, 64 and 66, which produce 6, 3 and 1.5 pulses per minute. The binary selector switch 62 is designed so that it will transmit the 6 pulse per minute signal in the absence of any signal from the trigger and latching circuit 61. Thus the absence of any inflow of material into

the well will be signaled by the production of six pulses per minute. When a signal is received from the trigger and latching circuit 61, the binary selector switch will be moved to the opposite position from that shown and three pulses per minute will be transmitted to the remainder of the circuit. The output of the binary selector switch 62 is connected to one position of a second selector switch 65. In its normal position the switch 65 will transmit the signal received from the binary switch 62 to the remainder of the circuit. If there is only a flow of gas or liquid into the well, it will affect primarily the acoustic transducer 32 and three pulses per minute will be transmitted to the remainder of the circuit.

The binary selector switch 65 is controlled by the resistivity sensing electrode 30. The resistivity electrode is coupled to one side of a 15 volt AC power supply through a large current limiting resistor 69 while the other side of the power supply is grounded. The voltage at the resistivity electrode is thus related to the conductivity of the fluid between it and ground. The resistivity electrode may comprise a 1/16 inch diameter electrode surrounded by a 1/4 inch O.D. insulator, both mounted flush with the outer wall of the drill collar. The electrode 30 is coupled to an amplifier 70 whose input is coupled to ground. The amplifier 70 is coupled to a comparing circuit 71 which is also supplied with a reference voltage indicated as a set point 72. The comparing circuit thus compares a measured resistivity with a predetermined value and supplies the difference as a signal to the binary switch 65. The set point for the comparing circuit should be set at the approximate value of the resistivity of the drilling mud so that when salt water flows into the borehole the resistivity will materially change and the comparing circuit will supply an output signal. The signal from the comparing circuit 71 will reposition the binary switch 65 to the opposite position from that shown so that it will transmit the pulses from the one one-half pulse per minute generator 66.

The binary switch 65 is coupled to a trigger circuit 73 which in turn is coupled to the switch 74. The switch 74 serves to switch the AC voltage to the valve solenoid 64 at the pulse frequency received from the binary switch 65. The trigger circuit 73 may be a conventional multivibrator circuit which supplies a single output pulse for each input pulse received to operate the switch 74. The switch 74, in turn, can be a solid state switching device, such as a silicon controlled rectifier for switching the high power AC voltage to the valve solenoid 24.

#### OPERATION

The above-described tool is operated by first installing the instrument sub in the drill string and the drill bit at the end of the instrument sub. The assembly is then lowered into the well and a conventional rotary drilling practice used. As the well is drilled, the two acoustic transducers 31 and 32 will be energized to produce acoustic waves in the drilling mud. As explained, the reference transducer 31 will produce acoustic waves in the drilling mud before it is circulated through the drill bit; while the transducer 32 will produce acoustic waves in the drilling mud after it is circulated through the drill bit and is returning to the surface. Thus, if there is any inflow of fluid, and particularly gas, into the wellbore, it will be present in the drilling mud viewed by transducer 32 while it will not be present in the drilling mud viewed by the reference transducer 31.

Any scattered or reflected acoustic energy received by the transducers will be materially different, and the difference signal can be used to indicate the present of an inflow into the well.

As described, three pulse generators are provided having frequencies of 6, 3 and one one-half pulses per minute. The binary switches 62 and 65 are designed so that they will transmit a six pulse per minute signal when there is no inflow of fluid into the well and both the transducers 31 and 32 receive approximately the same amount of scattered and reflected acoustic energy. When there is an inflow of fluid, particularly gas, the difference in the two received acoustic signals will be used to switch the binary switch 62 so that three pulses per minute are transmitted. The pulses transmitted by the binary switches are used to activate the valve mechanism 25 to produce a series of pressure pulses in the mud stream being circulated through the drill string and back to the surface. Well known equipment is available for detecting the pressure pulses at the surface as well as for producing pressure pulses in a mud stream in the downhole instrument. The valve 25 is merely one example that may be used.

Also described above is an electrical or resistivity logging device which measures the conductivity of the mud stream after it has passed through the drill bit. Normally the conductivity of the drilling mud will be known and the set point of the comparing circuit 71 set accordingly. When an inflow of fluid into the well, and particularly salt water or liquid petroleum products, occurs the resistivity will materially change. This change will be sensed by the comparing circuit 71 and the resulting signal used to position the binary switch 65. When the binary switch 65 is repositioned, it will transmit one one-half pulses to the circuit used for actuating the valve 25. This, in turn, will produce a frequency of one one-half pressure pulses per minute in the mud stream which can be detected at the surface.

From the above description of the operation, it can be seen that six pressure pulses per minute are produced in the mud stream when there is no inflow of fluid into the well, three pulses are produced when there is a flow of fluid, particularly gas, into the well, and one one-half pulses are produced when there is inflow of either salt water or liquid petroleum products. This choice of frequencies is merely for the purposes of illustration and various combinations can be developed, or the system expanded, so that more information can be transmitted. For example, it is possible to develop combinations of pulses which would indicate that there is an inflow of both gas and liquids into the well. Further, the liquids can be differentiated between salt water and liquid petroleum products.

I claim as my invention:

1. A method for detecting an inflow of fluid into a well during the drilling of the well by rotary means using a circulating drilling fluid, said method comprising:
  - producing pulses of acoustical energy and directing said acoustic energy into said drilling fluid both before it enters the drilling bit and after it has passed through the drilling bit;
  - measuring the difference between the acoustic energy reflected and scattered from the drilling fluid before it enters the drill bit and after it has passed through the drill bit and converting said measurements to a difference signal; and

transmitting a signal related to said difference signal to the surface.

2. The method of claim 1 and in addition measuring the resistivity of the drilling fluid after it has passed through the drill bit and transmitting a signal related thereto to the surface.

3. The method of claim 2 wherein said signals related to the difference signal and resistivity are transmitted to the surface by producing different frequencies of pressure pulses in the circulating drilling fluid.

4. The method of claim 1 wherein said pulses of acoustical energy are produced at two distinct locations, one location positioned to direct the acoustic energy into the drilling fluid before it has circulated through the drill bit and the other location positioned to direct the acoustic energy into the drilling fluid after it has been passed through the drill bit.

5. The method of claim 4 wherein said difference signal is transmitted to the surface in the form of a series of pressure pulses produced in the circulating drilling fluid.

6. An apparatus for detecting the inflow of fluid into a well during the drilling of the well using rotary means including circulating a drilling fluid down the interior of the drill stem through the drill bit and back to the surface through the annulus, said apparatus comprising:

transducer means, said transducer means being located at the lower end of the drill stem adjacent the drill bit and disposed to produce acoustic impulses that travel through the drilling fluid in both the interior of the drill stem and the annulus, said transducer means also receiving acoustic waves that are reflected and scattered by the fluid in both the drill stem and the annulus;

first circuit means coupled to said transducer means to energize the transducer means to produce said acoustic impulses and to amplify the reflected and scattered acoustic waves;

second circuit means for determining the difference between the reflected and scattered acoustic waves from the interior of the drill stem and the annulus and produce a difference signal related to the difference; and

signal transmitting means for transmitting the difference signal to the surface of said well.

7. An apparatus for detecting a fluid inflow into a well during the drilling of said well, said apparatus comprising:

transducer means disposed near the bottom of said well, said transducer means being disposed to transmit acoustic pulses through the fluid filling the well and receive the reflected and scattered acoustic waves, said transducer means generating a receiver signal related to the received acoustic waves;

reference signal means for generating a reference sig-

nal;  
comparison means for comparing the reference signal with the receiver signal and producing a signal related to the difference between the two signals; and

transmission means disposed in said well and coupled to the comparison means for transmitting the signal related to the difference between the two signals to the surface.

8. The apparatus of claim 7 and in addition a resistivity measuring means for measuring the resistivity of drilling fluid being circulated through the well adjacent the bottom thereof and supplying a resistivity signal related to the measurement; said resistivity measuring means being coupled to the circuit means, said comparing means also being coupled to said circuit means whereby said resistivity signal and said signal related to the difference between the receiver and reference signals may be combined in a single signal, said signal being supplied to said transmission circuit for transmission to the surface.

9. The apparatus of claim 7 wherein said transmission means comprises a system for producing pressure pulses in the drilling fluid being circulated through the well to transmit said signal related to the difference between said two signals to the surface.

10. The apparatus of claim 9 wherein the well is drilled with a rotary drill rig including a drill bit attached to the lower end of a drill stem with a drilling fluid being continuously circulated down the drill stem through the drill bit and returned to the surface through annulus formed by the borehole and drill stem, said pressure pulses being produced in the circulating drilling fluid by intermittent throttling of the flow of said drill fluid.

11. The apparatus of claim 10 wherein said signal related to the difference between the two signals comprises a first preset number of pressure pulses for indicating no inflow of fluid into the well and a second preset number of pulses for indicating an inflow of fluid that exceeds a minimum amount.

12. A method for detecting the inflow of fluid into a well filled with a drilling fluid comprising:

producing acoustical radiation in said drilling fluid; measuring the reflected and scattered acoustical radiation resulting from said impulses; detecting the change in the measured reflected and scattered acoustical radiation resulting from an inflow of fluid into the well; and,

utilizing said measured variation as an indication of an inflow of fluid into the well.

13. The method of claim 12 wherein the variation in the reflected and scattered radiation is measured by comparing the measured scattered and reflected radiation with a preset reference value.

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