May 17, 1966 W. B. BROOKS 3,251,424

ACOUSTIC DRILLING METHOD AND APPARATUS

Filed June 18, 1962

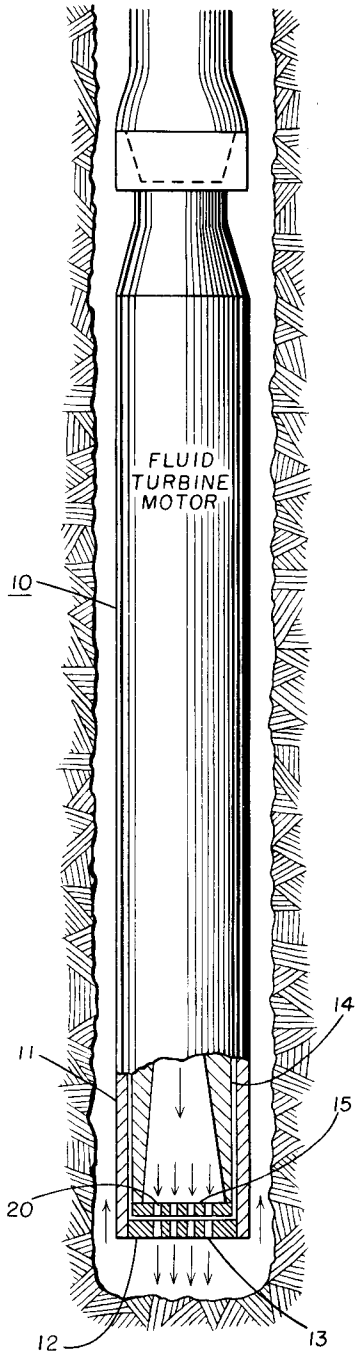


FIG. 1

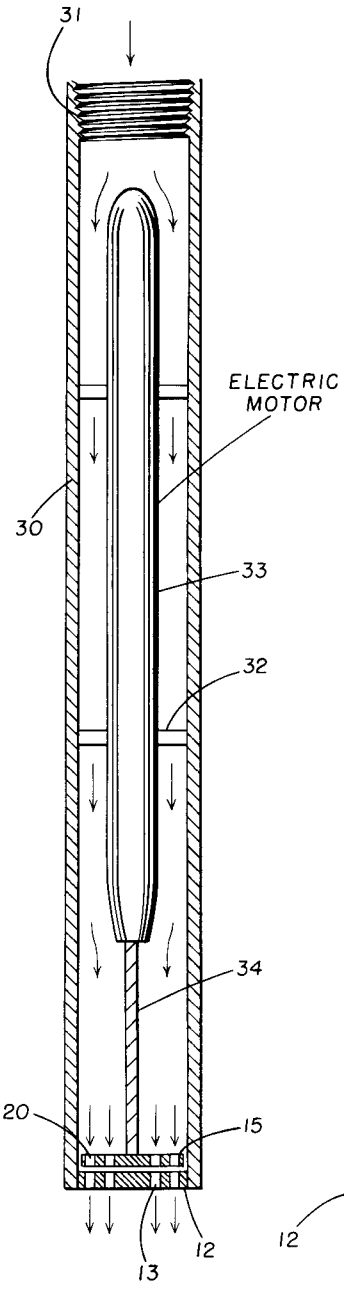


FIG. 2

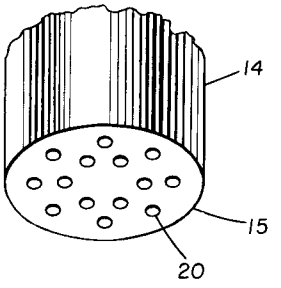


FIG. 3

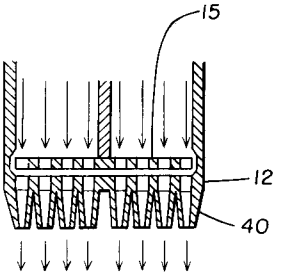


FIG. 4

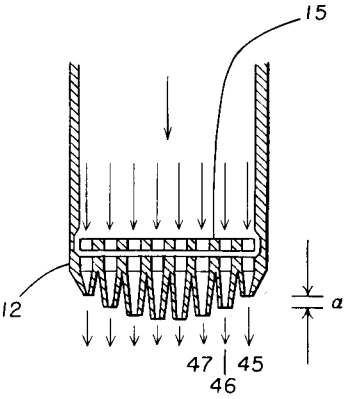


FIG. 5

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ACOUSTIC DRILLING METHOD AND APPARATUS

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3 Claims. (Cl. 175—56)

This invention relates to a method and apparatus for drilling a borehole in the earth. More specifically, this invention relates to a method and apparatus for drilling a borehole by means of fluid jet streams.

At the present time, the most commonly used method of drilling a borehole in the earth, particularly in the oil industry, is one which is referred to as rotary drilling. In rotary drilling, a drill bit having cutting surfaces is rotated in contact with the rock in an earth formation by means of a long column of drill collars and drill pipe which are powered by various types of equipment positioned on the surface of the earth. Other methods of drilling have been suggested and some are currently being used, but essentially all of them require a drill bit. A major disadvantage of and consequently one of the most expensive aspects of rotary drilling and most of the other presently employed methods is the necessity of changing the drill bit at frequent intervals. This obviously requires that all of the drill pipe and drill collars be removed from the borehole, the bit changed, and the drill pipe and drill collars again reinserted into the borehole before drilling can again commence.

It is one object of the present invention to provide a method and apparatus for drilling a borehole wherein a drill bit is not employed. It is another object of the present invention to provide a method and apparatus for drilling a borehole in which fluid jets are employed for the purpose of advancing the borehole through the earth.

In accordance with the present invention, drilling fluid is directed downwardly through a borehole toward the bottom thereof, the drilling fluid is formed into one or more jet streams, alternating high and low acoustic pressure pulses are generated within each of the jet streams, and each of the jet streams is directed against the bottom of the borehole to effect drilling of the earth formation.

In the drawing:

FIGURE 1 diagrammatically illustrates, in partial cross section, one embodiment of apparatus which may be utilized to carry out the present invention.

FIGURE 2 shows in cross section another embodiment of the apparatus of the invention.

FIGURE 3 is a partial perspective view of one portion of the apparatus illustrated in FIGURE 1.

FIGURES 4 and 5 are views in cross section of modifications which may be made in the apparatus illustrated in both FIGURES 1 and 2.

In carrying out the method of the invention, a drilling fluid, which may be either water or a mixture of a liquid and various solid materials generally referred to as drilling mud, is directed through a confined flow path along the length of a borehole toward the bottom thereof. At or near the lower end of opening of the flow path, the drilling fluid is formed into one or is separated into a plurality of relativey high velocity jet streams. Within each of the jet streams, a series of succession of alternating high and low acoustic pressure pulses are generated. Each of these acoustic pressure pulses comprises a dynamic pressure effected by means of sudden interruptions of the fluid movement within the jet streams that can be considerably larger than the hydrostatic pressure within the fluid. The jet streams in which the alternating acoustic pressure pulses are generated are then directed against the bottom of the borehole for the purpose of eroding away the rock and other materials comprising the earth formation being drilled.

The method of the invention may be carried out by several different forms of apparatus, including those illustrated in the drawing. Referring specifically to FIGURES 1 and 3, a fluid turbine type motor **10** is secured to the lower end of a string of drill pipe, not shown. The fluid turbine motor may be any one of several currently available to the industry. Examples of fluid turbine motors which may used are shown at page 3478, volume 2, and page 4845, volume 3, of The Composite Catalog of Oil Field Equipment and Services, 24th (1960–61) Revision, published by World Oil, Houston, Texas. Other examples of fluid turbine motors which may be employed are shown in U.S. Patent 2,908,534 to H. Rietsch, U.S. Patent 2,963,099 to S. J. Gianelloni, Jr., and at pages B–39 through B–44 of the October 1956 issue of the Petroleum Engineer.

Secured to the lower or outlet end of outer casing **11** of fluid turbine motor **10** is a fixed or stationary valve plate **12**. Valve plate **12** is provided with a plurality of apertures or openings **13**. Secured within the lower or outlet end of turbine rotor **14** is a rotatable valve plate **15** which is provided with a plurality of apertures or openings **20**. Openings **20** in valve **15** plate cooperate with openings **13** in valve plate **12** to separate the drilling fluid flowing through the turbine rotor **14** into a plurality of fluid jets. As rotor **14** is rotated, openings **20** pass in and out of registry with openings **13**, causing starting and stopping of the fluid jets to generate a succession of alternating high and low acoustic pressure pulses within the fluid jet streams. The positioning, number, and relationship of openings **20** and openings **13** will be discussed in further detail hereinafter. Valve plates **12** and **15** are positioned as close together as practicable with the distance between them being only that necessary to prevent undue friction between the plates due to the rotation of the plate **15**. In order to maintain correct alignment and positioning of plates **12** and **15** relative to each other, it may be desirable to provide some form of bearing, not shown, between the plates. Such a bearing, if necessary, might rest between the plates along their center line.

The actual drilling of a borehole by the method and apparatus disclosed herein is accomplished by the effect of the fluid jet streams produced by the drilling fluid passing through openings **20** and **13** in the valve plates. The number of jet streams, their placement, and the magnitude and frequency of the acoustic pressure impulses generated within the jet streams are dependent in part upon the positions, sizes, and number of the openings in the valve plates, together with the rotational speed of the movable valve plate. In one embodiment, the openings in each of the valve plates are arranged uniformly about concentric circles, as illustrated in FIGURES 1 and 3, with the holes in each of the valve plates being so positioned that for a given position of rotation of movable valve plate **15** relative to stationary valve plate **12** holes **20** will be in exact registry with holes **13**, causing simultaneous separation of the drilling fluid into a plurality of jet streams covering substantially the entire lower end of the drilling tool. In this form, the frequency of the alter-

nating acoustic pressure pulses generated within any particular jet stream flowing from the drilling tool is dependent upon the number of openings in the rotatable valve plate which pass into registry with an opening in the stationary valve plate during a complete rotation of the movable valve plate. The frequency of the alternating acoustic pressure pulses may be determined from the formula

$$f=nr$$

where

f=the frequency in any jet stream in cycles per second.
n=the number of equally spaced holes around any concentric circular section of the movable valve plate, and
r=the rotary rate of the movable valve plate in revolutions per second.

Assuming a drilling tool as illustrated in FIGURES 1 and 3 having an outer concentric circle of 30 holes and a rotational speed of 30 revolutions per second, the frequency of the alternating acoustic pressure pulses generated within each of the fluid jets passing through the holes in the outer concentric circle will be as follows:

$$f=nr=30\times30=900 \text{ cycles per second}$$

The actual acoustic pressure developed within each of the fluid jets is determined in accordance with the equation

$$P=\frac{\rho CV}{g}$$

where

P=the acoustic pressure,
ρ=the density of the drilling fluid,
C=the velocity of sound in the drilling fluid,
V=the change in velocity of the fluid due to operation of the mechanism, and
g=acceleration due to gravity.

For a particular tool designed with holes sized to effect fluid flow therethrough of 100 feet per second and utilizing water as the drilling fluid, the approximate pressure obtainable will be

$$P=\frac{0.036 \text{ lb./in.}^3\times5000 \text{ ft./sec.}\times1200 \text{ in./sec.}}{32.2 \text{ ft./sec./sec.}}=6700 \text{ p.s.i.}$$

In considering hole placement and design in the valve plates, it will be obvious that there may be numerous different patterns of fluid jets, frequencies, and combinations whereby the jets are either in phase with each other or out of phase. Obviously, a fluid jet is created only when a hole **20** in movable valve plate **15** comes into registry or partial registry with a hole **13** in fixed valve plate **12**. The total number of fluid jets available for drilling is dependent upon the number of holes provided in the lower or fixed plate **12**, while the frequency of the acoustic pressure pulses generated within a fluid jet stream is dependent upon the number of holes in the movable plate **15** which register with any one hole in plate **12** during a revolution of the movable plate. Considering the above-discussed formulas, the frequency of the acoustic impulses generated within a fluid jet stream may readily be varied by changing the number of holes in the movable plate while the magnitude or amplitude of the acoustic pressure pulses may be controlled by the sizing of the holes which affect the velocity of the drilling fluid through the holes. If the same number of holes is placed in the inner circle as in the outer circle and the holes are placed at the same angle about the plates, the frequencies of the acoustic pressure pulses generated within the fluid jet streams will be the same for all of the jet streams. On the other hand, by making the number of holes in the inner concentric circle different from the number in the outer concentric circle and varying their angular position about the plates, it is obvious that the frequencies of the acoustic impulses generated in the fluid jets coming from the holes in the two

circles will be different and they also will be out of phase with each other.

In carrying out the method of the invention, a drilling tool as illustrated in FIGURE 1 is secured to the lower end of a string of conventional drill pipe, not shown, and the drilling tool is lowered in a conventional manner into the borehole. Drilling fluid, which may be water or any other form of drilling fluid desired, is pumped through the drill string into the fluid turbine motor. The drilling fluid passes through the turbine of the fluid turbine motor, causing the turbine rotor **14** to rotate at the particular speed for which the tool is designed. The drilling fluid passes through the rotor **14**, toward valve plate **15** which is secured to and rotates simultaneously with the rotor **14**. As the holes **20** in valve plate **15** are rotated into registry with the holes **13** in fixed valve plate **12**, a plurality of fluid jet streams are created. By positioning the drilling tool in the proximity of the bottom of the borehole, the fluid jet streams are directed against the bottom of the borehole, causing the failure of the formation. As the formation fails due to the acoustic energy from the fluid jet streams, the cuttings, as they are generally referred to, are washed out by the drilling fluid and passed upwardly in the annulus, around the fluid turbine motor and the string of drill pipe, back to the surface. As the rotor **14** continues rotation, the holes **20** will pass out of registry with the holes **13**, effecting sudden stoppage of the flow of drilling fluid through the valve plate; and, of course, with further rotation of the rotor **14**, the holes will again pass into registry with the sudden opening of the holes, causing the sudden creation again of the fluid jet streams. Obviously, with the alternate opening and closing of the holes, the fluid jet streams are not only created, but alternating acoustic pressure pulses are generated within the fluid jet streams with the amplitude or magnitude of the acoustic pressure pulses alternating above and below the hydrostatic pressure of the fluid within the drilling tool. The alternating high and low acoustic pressure pulses generated within the jet streams will more effectively erode away the formation than the steady fluid streams employed in previously used jet drilling tools.

Another form of apparatus which may be employed in carrying out the method of the invention is illustrated in FIGURE 2. With respect to this particular embodiment of the apparatus of the invention, the description thereof will employ identical reference numerals to those used in connection with FIGURE 1 for parts functioning identically to those shown in FIGURE 1. Outer tool casing **30** is provided at its upper end with threads **31** to permit connection to the lower end of a string of conventional drill pipe. Secured at the lower end or discharge end of casing **30** is a fixed or stationary valve plate **12** which is provided with apertures or holes **13**. Casing **30** serves not only as the outer casing for the tool and support member for the stationary valve plate, but also functions to define a flow path for drilling fluid through the tool toward the stationary valve plate. Supported within outer casing **30** on spokelike brackets **32** is an electric motor **33** which is a relatively long, slender type motor having an outer diameter sufficiently less than the internal diameter of outer casing **30** to provide ample space between the motor and the inside of the casing to permit flow of drilling fluid through the tool around the motor. Supported on motor shaft **34** is a rotatable valve plate **15** which is provided with a plurality of apertures or openings **20**. The description and function of both valve plate **12** and valve plate **15** are identical to those given hereinabove in connection with the discussion of the apparatus illustrated in FIGURE 1. Electric motor **33** serves to rotate valve plate **15** to generate a succession of alternating high and low acoustic pressure pulses within the drilling fluid flowing through the tool in the manner described above. Electric current may be conducted to electric motor **33** by any of the conventional means employed in operating downhole electric motors.

Illustrated in FIGURES 4 and 5 are variations in the design of the lower stationary valve plate **12** which may be made for the purpose of changing the operating characteristics of either of the tools illustrated in FIGURES 1 and 2. In the apparatus illustrated in both FIGURES 4 and 5, the upper rotatable valve plate **15** remains unchanged. Referring specifically to FIGURE 4, lower stationary valve plate **12** is modified by providing over each of the holes therethrough a nozzlelike extension **40** which has a progressively decreasing cross section for the purpose of increasing the velocity of the fluid passing through a hole and its associated nozzle member. By increasing the fluid velocity through the hole and its associated nozzle member, the alternating acoustic pressure is increased as will be obvious from a re-examination of the formula discussed above on which this pressure is based. Since the alternating acoustic pressure obtainable is directly proportional to velocity, by increasing the velocity with nozzle members **40** the alternating acoustic pressure is increased.

The modification of plate **12** as illustrated in FIGURE 5 is designed with varying length nozzles such that a stairstep type hole is drilled. A further feature of the apparatus illustrated in FIGURE 5 is that the formation is simultaneously subjected to positive and negative acoustic pressures on adjacent areas of the bottom of the formation below the jet nozzles. The nozzles **45** which comprise the outer row of nozzles on the fixed valve plate may be of any length and cross-sectional area desired. Nozzles **46** which make up the second row of nozzles adjacent to the row of nozzles **45** are, however, longer than nozzles **45** by a distance *a* which is equivalent to one-half of the wave length of the acoustic pressure pulses generated within the jet streams. The length of nozzles **46** relative to nozzles **45** may be readily determined in accordance with the following formula:

$$d=\frac{\lambda}{2}=\frac{C}{2f}$$

where

f=the frequency of the alternating acoustic pressure pulses generated by the drilling tool,

λ=the wave length of the acoustic energy generated, and

C=the velocity of sound in the drilling fluid being used in the tool.

By way of illustration, using water as a drilling fluid and assuming a drilling tool constructed in accordance with the invention produces fluid jets having acoustic pressure pulses generated therein at a frequency of 2500 cycles per second, the distance d may be determined as follows:

$$d=\frac{C}{2f}=\frac{5000}{2\times 2500}=1 \text{ foot}$$

Therefore, when nozzles **46** are constructed to be one foot longer than nozzles **45**, the acoustic pressure pulses generated in nozzles **45** and **46** will be out of phase one-half wave length from each other. In other words, when the acoustic pressure pulse in the fluid jets from nozzles **45** is at a maximum on the positive side, the acoustic pressure pulse in the fluid jets from nozzles **46** will be at a maximum on the negative side. In order for the acoustic pressure pulses in the jets produced by nozzles **47** to be one-half wave length out of phase with those from nozzles **46**, it will be obvious that nozzles **47** will be longer than nozzles **46** by a distance equal to one-half the wave length which, in the above example, is one foot. Obviously, other combinations of phase relationships between the acoustic pressure pulses generated by the various nozzles may be obtained by adjustment of the lengths of the nozzles. It may be observed that in connection with the stairstep type nozzle arrangement as shown in FIGURE 5, the making of the nozzle lengths one-half wave length difference in distance for adjacent rows of nozzles would appear to be practical only in the higher frequency ranges. This is because of the unwieldly lengths of nozzles which would be required in the lower frequency ranges. For example, in the above example the nozzles lengths differ by one foot for a 2500-cycle per second frequency, and if this were reduced to 1000 cycles per second frequency the nozzle lengths would vary by 2½ feet. Obviously this can reach an impractical limit.

Another means of subjecting adjacent portions of the bottom of the hole to high and low values of acoustic pressure is by designing the rotating plate such that adjacent holes are not in registry at the same time, as mentioned previously.

While the apparatus of the invention has been illustrated in terms of various embodiments of a combination of a fixed and a rotating valve plate, it will be obvious that other forms of apparatus may be employed for the purpose of generating acoustic pressure pulses within the fluid jet streams developed by the apparatus. For example, movable valve plate **15** rather than being rotated relative to valve plate **12** might be a sliding, eccentrically driven valve plate. Such a sliding valve plate might be powered through an eccentric by either electric or fluid turbine motor means and may be provided with one or more openings. Also, it will be obvious that while downhole motor means have been illustrated herein and are to be preferred, it would be possible to actuate a valve plate such as rotatable valve plate **15** by mechanical means from the surface of the earth, such as by a shaft extending down through the drill string to the valve plate. Other means for generating acoustic pressure pulses within fluid jets will, of course, occur to those skilled in the art.

What is claimed is:

1. In a method of drilling a borehole the steps which comprise

(a) conducting a stream of drilling fluid along a borehole toward the bottom thereof;

(b) separating said drilling fluid into a plurality of jet streams;

(c) generating within one portion of said jet streams alternating high and low pressure acoustic pulses;

(d) generating within another portion of said jet streams high and low pressure acoustic pulses, said acoustic pulses being out of phase relationship with the acoustic pulses generated during step (c); and

(e) directing said jet streams against the bottom of said borehole.

2. In apparatus for fluid jet drilling the combination which comprises

(a) conduit means for conducting drilling fluid through a borehole toward the bottom thereof;

(b) a fixed plate secured across said conduit means near the lower end thereof, said plate being provided with a plurality of openings to divide said drilling fluid into jet streams and direct said jet streams against the bottom of said borehole;

(c) a nozzle element secured over each of said openings in said fixed plate to increase the velocity of said jet streams;

(d) a rotatable plate positioned above and adjacent to said fixed plate, said rotatable plate being provided with a plurality of openings adapted to register with said openings in said fixed plate at a given position of rotation of said rotatable plate relative to said fixed plate; and

(e) power means connected to said rotatable plate for rotating said plate relative to said fixed plate.

3. In the apparatus of claim **2** wherein

(a) the openings in said fixed plate and said rotatable plate are arranged in concentric circular rows around the centers of said plates; and

(b) the length of the nozzle elements over each of said rows of openings in said fixed plate differs from the length of the nozzle elements over an adjacent row of openings by a distance equal to one-half the wave

length of the acoustic energy generated in said jet streams, the lengths of said nozzle elements progressively decreasing in length from the row nearest the center of said plate to the outermost row of said plate.

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