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METHOD AND APPARATUS FOR THE EXPLOSIVE DRILLING OF BOREHOLES

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2 Sheets-Sheet 1

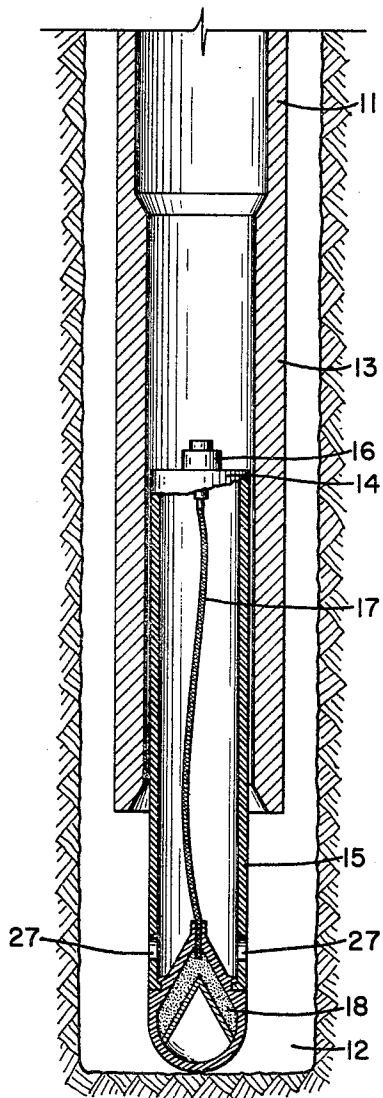


FIG. 1

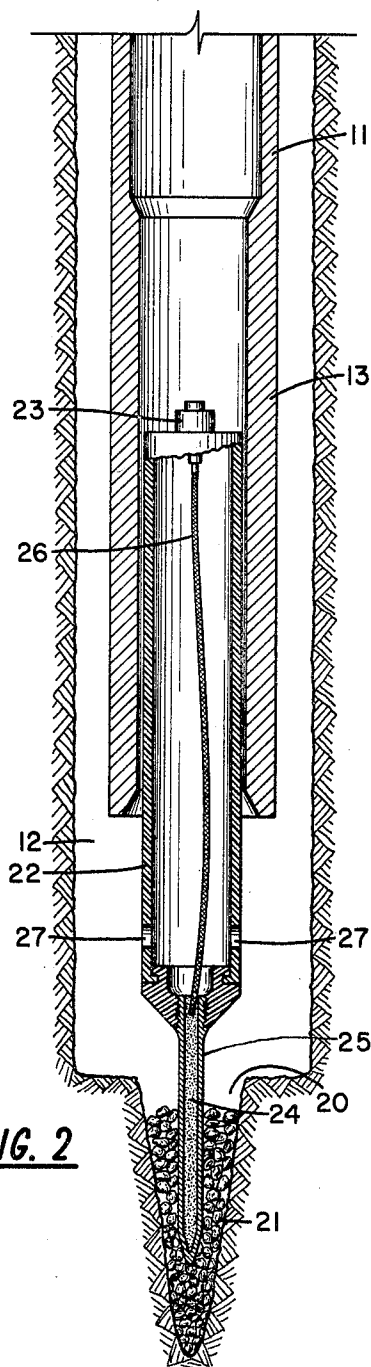


FIG. 2

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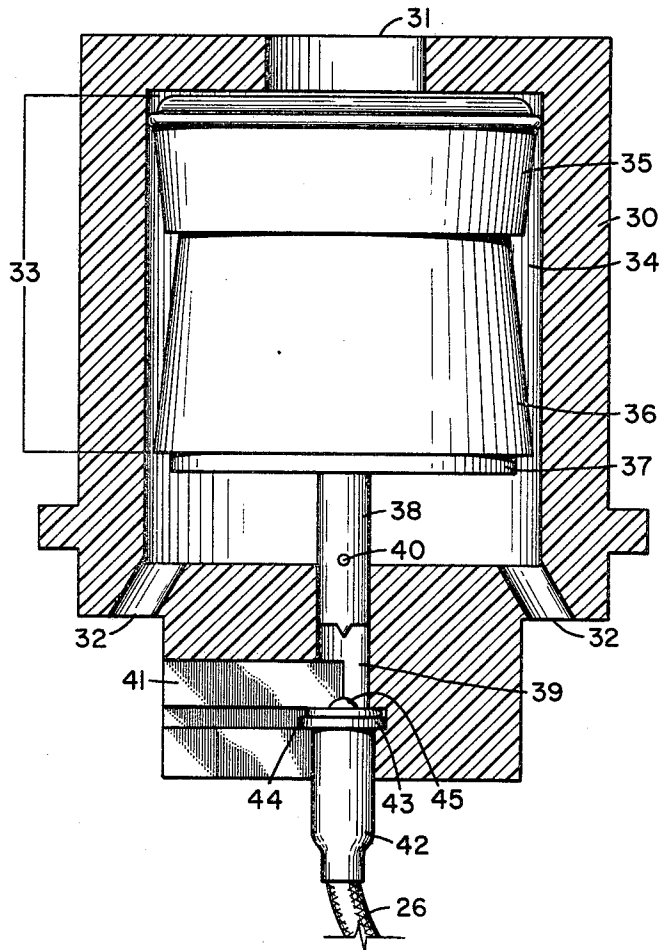


FIG. 3

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3,491,841 METHOD AND APPARATUS FOR THE EXPLOSIVE DRILLING OF BOREHOLES

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6 Claims

ABSTRACT OF THE DISCLOSURE

A method and apparatus for enlarging a hole created by a shaped explosive charge at the bottom of a borehole in the earth by forcing a capsule provided with a non-directional explosive charge at its lower end down a well pipe until the charge penetrates debris remaining in the shaped charge hole and extends substantially the length of the shaped charge hole, and thereafter detonating the explosive charge.

BACKGROUND OF THE INVENTION

Field of the invention

This invention relates to the drilling of boreholes in the earth and is particularly concerned with the explosive drilling of boreholes with directional charges that penetrate the rock at the bottom of the borehole and non-directional charges that enlarge the holes formed by the shaped charges.

Description of the prior art

The use of explosive charges for the drilling of boreholes in the earth is known in the art. The most successful system yet proposed uses two types of explosive charges—a directional charge and a gauging charge. In this system, the directional, shaped charge explosive capsule is first pumped down the well pipe to the bottom of the borehole so that its upper end remains in the well pipe and forms an obstruction to the flow of the circulating fluid. This obstruction creates a pressure differential between the fluid in the well pipe and the fluid in the borehole below the capsule. When this differential pressure reaches a preset level required to actuate a firing mechanism in the capsule, the directional charge detonates, creating a deep, narrow hole in the rock at the bottom of the borehole.

Following detonation of the directional charge as described in the preceding paragraph, drilling fluid is circulated for a period of time sufficient to remove the debris from the borehole. An explosive capsule containing a non-directional gauging charge is then pumped down the well pipe into the hole previously formed. This gauging charge is detonated in response to the buildup of pressure across the capsule. The resulting explosion enlarges the diameter of the hole created by the shaped charge so that it will accommodate the well pipe as it is lowered. After the debris has again been circulated from the wellbore, another shaped charge is pumped to the bottom and the drilling cycle continues.

In the method discussed above, drilling fluid is circulated for a period sufficient to clean the borehole and thus permit penetration of the non-directional charge into the shaped charge hole. It has been found that removal of the debris is difficult because the well pipe cannot be lowered into the shaped charge hole. The circulating fluid tends to flow into the annulus surrounding the pipe without entering the smaller hole and hence much of the shattered material is not entrained. The presence of this debris retards entry of the non-directional capsule into the shaped charge hole and may therefore restrict the

effect of the non-directional charge to the upper part of the hole. This limits the penetration rate obtained and necessitates the use of more explosives than would otherwise be required.

SUMMARY OF THE INVENTION

This invention provides a method and apparatus for at least in part overcoming the difficulties outlined above. In accordance with the invention, it has now been found that capsules containing non-directional charges can be forced down the well pipe and into the debris remaining in shaped charge holes until they substantially penetrate to the bottoms of the shaped charge holes and then detonated, thereby alleviating difficulties normally encountered in circulating the debris to the surface and permitting higher drilling rates than have generally been obtained in the past.

The non-directional explosive capsule employed for purposes of the invention includes an elongated housing, a non-directional explosive charge mounted at the lower end of the housing, means for inducing initial penetration of the explosive charge into debris left in the shaped charge hole, and means for detonating the explosive charge after the explosive charge extends substantially the length of the shaped charge hole. The means for inducing initial penetration of the explosive charge include a long needlelike housing attached to the lower end of the capsule which contains the charge. This maximizes initial penetration of the gauging capsule due to its momentum upon arrival at the bottom of the well pipe. Tests have shown substantial additional penetration can be induced by delaying detonation of the explosive charge with a pyrotechnic time delay or other delay means for a short time after initial capsule impact. The additional penetration apparently results from differential pressure between the well pipe and the borehole in excess of that which is normally required to detonate the charge. The downward resultant force due to this additional pressure is exerted along the longitudinal axis of the capsule, driving it deeper into the debris remaining in the directional explosive hole.

The method and apparatus of the invention result in greater penetration of the gauging charge into the directional charge hole and thereby permit more efficient utilization of the explosive for enlarging the hole to gauge. This in turn improves the penetration rate obtainable by explosive drilling and provides economic advantages over explosive drilling systems utilized in the past.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional elevation showing a directional charge explosive capsule in position before the charge is detonated at the bottom of the borehole. FIG. 2 is a cross-sectional elevation depicting a gauging explosive charge as it moves downwardly through debris remaining in the directional explosive hole. FIG. 3 depicts in cross section a differential pressure actuated firing mechanism suitable for use in the gauging charge capsules of FIGS. 1 and 2.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The apparatus shown in FIG. 1 of the drawing includes a well pipe 11 suspended in a borehole 12. The pipe may include an internally restricted section 13 for reducing the annular flow area between an explosive capsule 14 and the wall of the pipe and thus increasing the pressure drop across the capsule near the lower end of the pipe but such a restriction is not essential. The pipe may instead be of substantially uniform inside diameter over its entire length if desired. The capsule depicted

includes an elongated housing 15 of cylindrical or polygonal cross section and a differential pressure actuated firing mechanism 16 positioned near the upper end of the housing. An explosive chain 17 connects this firing mechanism to a directional charge 18 near the lower end of the capsule. The components of this directional charge capsule, except for the explosive charge, may be similar to those of the nondirectional charge capsule shown in FIG. 2, discussed below. The shaped charge in the capsule of FIG. 1 may be of conventional design.

FIG. 2 depicts the wellbore, after the directional charge shown in FIG. 1 has been detonated, as a nondirectional charge capsule moves downwardly through the debris 20 remaining in the small-diameter shaped charge hole, indicated by reference numeral 21. The nondirectional charge capsule shown includes a hollow cylindrical housing 22 to which a differential pressure actuated firing mechanism 23 is attached near its upper end. An explosive charge 24 contained in an elongated, needle-shaped housing 25 of aluminum, copper, or similar metal is threaded or otherwise attached to the bottom of the cylinder. An explosive chain including line explosive 26 connects the firing mechanism to the explosive charge. The housing 22 preferably is made of polystyrene or a similarly frangible material which will be reduced to small fragments that can be circulated from the enlarged portion of the borehole adjacent the pipe and carried up the annulus between the pipe and the borehole wall following detonation of the charge. Fluid entry ports 27 located near the lower end of housing 22 permit circulating fluid to enter the housing. These ports insure pressure communication between the underside of the differential pressure actuated firing mechanism and the lower portion of the borehole 12.

The differential pressure actuated firing mechanism 23, shown in greater detail in FIG. 3 of the drawing, includes a substantially cylindrical outer housing 30 having a single pressure detection port 31 in its upper end and two pressure detection ports 32 near its lower end. A piston assembly 33 is slidably disposed within the vertical inner cylindrical well 34 formed by outer housing 30. The piston assembly is at least partially resilient and in this embodiment is made up of a substantially nonresilient upper member 35 which provides a slidable seal with the inner wall surface of well 28 and a resilient lower member 36 of slightly smaller diameter. A rigid circular plate 37 is mounted on a firing pin 38 below the piston assembly. It should be apparent that other piston assemblies which are at least partially resilient may also be used.

The firing pin 38 extends downwardly within an opening 39 of reduced diameter in the base of housing 30. This firing pin is held in a fixed position prior to actuation of the device by a shear pin 40. Port 41 is provided so that circulating fluid beneath the firing pin can escape. A cartridge 42 is mounted under firing pin 38 by means of a washer 43 resting in slot 44 in the base of the housing. A primer 45 is located in the uppermost part of cartridge 42 and is detonated by firing pin 38 when shear pin 40 fails. Cartridge 42 is preferably a commercial grade 22 caliber "Hornet" but other types of cartridges may also be used.

A time delay means is provided in the firing mechanism of the gauging charge capsule in one preferred embodiment of the invention. This is preferably done by packing cartridge 42 with a pyrotechnic mixture that detonates without producing any gas and that will create a time delay between primer 45 and an igniter charge. A combination of antimony, potassium permanganate, and magnesium silicate is generally preferred. The addition of a mixture of 34 percent antimony, 63 percent potassium permanganate, and 3 percent magnesium silicate by weight has yielded a time delay of approximately two seconds under hydrostatic pressures in the order of 1000 p.s.i.g. This is generally adequate. Other pyrotechnic delay mixtures are also suitable, some of which are described on

pages 283 and 284 of the text "Modern Pyrotechnics" by H. Ellern, Chemical Publishing Company, Inc., New York, N.Y., 1961.

The explosive chain in the capsule of FIG. 2 may include an igniter charge, normally contained in cartridge 42 and therefore not shown, and a line explosive 26. The igniter charge is used when neither the cartridge primer 45 nor the pyrotechnic time delay mixture is sufficient to detonate the line explosive. A few granules of lead azide and RDX can, because of their high sensitivity, be readily initiated by the primer and used in turn to ignite the line explosive. These igniter explosives or other high-sensitivity primary explosives are generally packed into the cartridge between the line explosive and the primer, or where a pyrotechnic time delay is provided, between it and the line explosive. The use of a more powerful primer would, of course, obviate the need for an igniter charge.

Line explosive 26 is crimped into the end of cartridge 42. It extends the length of housing 22 to explosive charge 24. An explosive sold under the trade name of Primacord, manufactured by Ensign-Bickford Company of Simsbury, Conn., is preferably used but other line explosives are also suitable. Explosive charge 24 is located within the narrow cylindrical needlelike end of metallic housing 25 on the gauging capsule. The charge can be composed of brisant, unbrisant, or a mixture of brisant and unbrisant explosives, but the preferred explosive is known by the trade name Pentolite and is composed of 50% PETN and 50% TNT. Cyclotol, a trade name for a composition of 60% TNT and 40% RDX by weight, can also be used, as may many other explosives.

In carrying out the method of the invention, a shaped charge explosive capsule is first pumped down the well pipe to the bottom of the borehole as depicted in FIG. 1. The upper end of the capsule normally remains in the well pipe within restricted lower section 13. The use of such a restricted section permits the use of a relatively light capsule housing without danger of premature collapse of the capsule and is therefore advantageous but in some cases it may be preferred to design the capsule for use with a well pipe of substantially uniform inside diameter over its entire length. The shaped charge explosive 18 in the lower end of the capsule comes to rest on the bottom of borehole 12.

As fluid is circulated in the wellbore, the pressure within the well pipe above the explosive capsule rapidly builds up as a result of the flow restriction created by the capsule. In the borehole below the capsule, the fluid remains at a lower pressure. The underside of piston assembly 33 in the firing mechanism of FIG. 3 communicates with the bottom of the borehole through the ports 32, while the upper side of piston assembly 33 is in fluid communication with the well pipe through upper pressure detection port 31. A differential pressure is therefore exerted across the piston assembly. The resultant force caused by this differential pressure is imparted to circular plate 37 through elastic member 36, which transmits it through firing pin 38 to shear pin 40. When the differential pressure reaches a predetermined value, the resultant force shears the shear pin and elastic member 36 snaps firing pin 38 against primer 45. This discharges the primer and the whole explosive chain sequentially detonates, causing shaped charge 18 to blast a deep, narrow hole 21 in the rock at the bottom of the borehole as depicted in FIG. 2. The fragments of the directional explosive capsule and the debris in the enlarged part of the borehole are carried up the annulus by the circulating fluid.

Following detonation of the directional charge, a gauging capsule is pumped into place at the bottom of the borehole as shown in FIG. 2. The narrow cylindrical lower tip of explosive housing on the gauging capsule normally comes to rest after spending its momentum in partially penetrating debris remaining in the hole left by the shaped charge. The upper end of the capsule containing the firing mechanism remains in the well pipe, causing a restriction

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of the flow of drilling fluid and a resulting differential pressure across the capsule.

The chain of events leading to the detonation of the gauging explosive capsule is similar to that for the shaped charge capsule except for a delay in the detonation of the gauging charge. Preferably, this delay occurs between the striking of primer 45 and the ignition of the line explosive. This allows the differential pressure to build up to a maximum value so that the resultant force drives the tip of the capsule deeper into the debris remaining in shaped charge hole 21. The explosive charge is detonated after it has penetrated substantially the entire depth of the shaped charge hole, resulting in more effective utilization of the explosive. The extent to which detonation of the gauging charge is delayed is generally limited by the tendency of the capsule to collapse if the differential pressure exceeds the capsule collapse strength, which in the preferred capsule is approximately 350 p.s.i. The viscosity of the drilling fluid, its circulation rate, and the clearance between the capsule and the well pipe, as well as capsule collapse strength, should therefore be considered in designing the delay mechanism.

Although the preferred method for detonating the explosive charge after the desired penetration of the shaped charge hole has been obtained involves the use of a differential pressure actuated firing mechanism and explosive chain with a pyrotechnic time delay therebetween, other techniques can be used. In some cases for example, it may be preferred to employ mechanical means for delaying detonation of the nondirectional charge after the required differential pressure is obtained or to manually control the fluid circulation rate so that sufficient pressure to force the capsule through the debris without detonating the explosive charge is generated initially and additional pressure sufficient to detonate the charge is built up later. In other cases it may be preferred to use a different kind of firing mechanism, e.g., an electrically actuated firing mechanism. These and other modifications of the specific method and apparatus described above will be apparent to those skilled in the art.

What is claimed is:

1. A method of drilling with shaped explosive charge capsules and elongated, nondirectional explosive charge capsules through a well pipe lowerable into a borehole comprising:

- (a) forcing a shaped charge capsule down the well pipe until it strikes the bottom of the borehole, the upper end of the capsule remaining within the well pipe;
- (b) detonating the shaped charge to blast earth material below the well pipe;
- (c) after detonation of the shaped charge, forcing a nondirectional explosive charge capsule down the well pipe and into contact with debris at the bottom of the borehole, the upper end of said capsule remaining within the well pipe;
- (d) increasing pressure within the well pipe to a level sufficient to force the explosive charge to penetrate debris remaining in the shaped charge hole until the explosive charge extends substantially the length of the shaped charge hole; and
- (e) thereafter, detonating the nondirectional charge.

2. A method for enlarging a hole containing debris created by a shaped charge at the bottom of a borehole in the earth below a well pipe with a capsule containing a nondirectional explosive charge within its lower end comprising:

- (a) forcing the capsule down the well pipe into contact with debris at the bottom of the borehole, the upper end of said capsule remaining in said well pipe;
- (b) increasing pressure within the well pipe to a level sufficient to force the explosive charge to penetrate debris remaining in the shaped charge hole until the explosive charge extends substantially the length of the shaped charge hole; and
- (c) thereafter, detonating the explosive charge.

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3. A method for enlarging a hole containing debris created by a shaped charge at the bottom of a borehole in the earth below a well pipe with an elongated explosive capsule having a nondirectional explosive charge housed within its lower end comprising:

- (a) forcing the capsule down a well pipe until said capsule comes to rest in debris remaining in the shaped charge hole, the upper end of said capsule remaining in said well pipe;
- (b) increasing the pressure within the well pipe to a level sufficient to force the explosive charge to extend substantially the length of the shaped charge hole; and
- (c) thereafter, detonating the nondirectional explosive charge.

4. An explosive capsule for use in explosive drilling operations to enlarge the hole created by a shaped charge comprising:

- (a) an elongated housing;
- (b) an explosive charge mounted at the lower end of end of said housing;
- (c) means for inducing initial penetration of the explosive charge into debris left in a shaped charge hole;
- (d) means for detonating the explosive charge after the explosive extends substantially the length of said shaped charge hole, said means including a differential pressure-actuated firing mechanism including
 - (i) a hollow outer housing having at least one fluid inlet port in each end, said housing containing a vertical well within it;
 - (ii) an at least partially resilient piston assembly slidably housed within said well;
 - (iii) a firing pin slidably mounted in an aperture in the lower end of said outer housing, said firing pin held in a fixed position by a shear pin;
 - (iv) a rigid plate separating the piston assembly from said firing pin, said plate being slidable within said inner well to transmit force from piston member to firing pin; and
 - (v) means including a time delay to ignite an explosive chain in response to longitudinal motion of the firing pin in response to differential pressure across the piston assembly sufficient to rupture the shear pin.

5. An explosive capsule for use in the explosive drilling of boreholes in the earth comprising:

- (a) an elongated capsule housing of polystyrene or a similar readily frangible material, said housing including means for the attachment of a firing mechanism near the upper end thereof, a fluid port in the capsule housing wall near the lower end thereof, and means for the attachment of an explosive charge housing at the lower end thereof;
- (b) a firing mechanism attached near the upper end of said capsule housing, said mechanism including a detonator housing of polystyrene or a similar readily frangible material having an opening in the upper end thereof, a fluid port near the lower end thereof, a resilient piston positioned intermediate said opening and said fluid port, a firing pin connected to and extending below said resilient piston, a rigid plate separating the piston from said firing pin, a metallic cartridge containing a primer positioned in said detonator housing below said firing pin, and means for retaining said firing pin in position above said cartridge until said resilient piston moves downwardly in said detonator housing in response to differential pressure;
- (c) an explosive charge housing containing an explosive charge connected to the lower end of said housing; and
- (d) an elongated line explosive extending downwardly in said capsule housing between said firing mechanism

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nism and said explosive charge, the upper end of said line explosive being crimped in place in said metallic cartridge.

6. A method of drilling with shaped explosive charge capsules and elongated nondirectional explosive charge capsules through a well pipe lowerable into a borehole comprising:

- (a) introducing a frangible capsule containing a shaped charge near the lower end thereof into the well pipe;
- (b) pumping fluid into the well pipe behind said capsule until said capsule strikes the bottom of the borehole, the upper end of the capsule remaining within the well pipe;
- (c) continuing to pump fluid into the well pipe until the differential pressure between the well pipe and the borehole causes the shaped charge to detonate;
- (d) pumping additional fluid into said well pipe to remove a portion of the debris created by said shaped charge and the fragments of said capsule from the bottom of the borehole;
- (e) pumping a frangible capsule containing a non-

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directional explosive charge near the lower end thereof down the well pipe until said capsule strikes debris at the bottom of the borehole, the upper end of the capsule remaining within the well pipe; and (f) continuing to pump fluid into the well pipe until the differential pressure between the well pipe and the borehole causes said capsule to move downwardly a substantial distance into said debris and said nondirectional charges to thereafter detonate.

References Cited

UNITED STATES PATENTS

3,070,010	12/1962	Robinson	175—4.5
3,070,011	12/1962	Robinson et al.	175—4.6 X
3,185,224	5/1965	Robinson	175—4.54
3,190,372	6/1965	Johnson	175—4.5

DAVID H. BROWN, Primary Examiner

U.S. Cl. X.R.

175—4.54, 6