The shaped electrodes can take various forms with the important feature being that the central electrode and/or the surrounding dielectric material is provided with a conical shape. The apex of the cone is directed towards the target. Preferably, the central electrode is disposed at the apex of the cone with the tip of the electrode terminating flush with the surface of the cone. The second electrode can be either a ground electrode which is disposed outside the cone with its lower end extending below the lower edge of the cone or may be a cylindrical electrode that surrounds the dielectric material. In the case of a cylindrical electrode the lower end or tip of the cylinder should extend slightly below the lower end of the cone. In addition to the use of the shaped electrode arrangement, the center electrode can also be provided with a fluid passage in order that the electrode can be combined with a normal jet hit. In this arrangement the discharge would serve to break the hard earth formations while the jet would drill the softer formations. In both cases the drill cuttings would be conveyed out of the borehole by the jet fluid. Likewise, the shaped electrode assembly could be combined with a conventional roller cone bit in which the roller cones would insulate the drilling of the proper gage borehole while the spark discharge was used to break the hard earth materials.

DESCRIPTION OF THE DRAWINGS

The present 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:

FIGURE 1 is a cross section of a shaped electrode assembly constructed according to this invention; FIGURE 2 is a cross section of a shaped electrode assembly constructed according to this invention combined with a conventional jet bit; and

FIGURE 3 is an elevation view of a borehole showing the shaped electrode assembly of this invention combined with a conventional roller cone bit.

DESCRIPTION OF PREFERRED EMBODIMENTS

As explained above when a spark discharge occurs between a pair of electrodes that are immersed in a liquid, a high-temperature, high-pressure plasma is formed between the electrodes. When the electrodes are conventional rod-shaped electrodes, the plasma will expand in a general spherical form and create a spherical pressure wave as the ionized fluid expands. In a relatively incompressible fluid, as for example, water, the expanding plasma will create a high-energy shock wave that can be used to do useful work. For example, the shock wave has been used as a source of seismic energy and in metal forming operations. In addition, the shock wave has been used to drill boreholes either by itself or in combination with other types of drills.

While the above systems of spark discharges have been used as explained above, they are relatively ineffective due to the dissipation of the major portion of the energy in directions other than towards the target.

The present invention is designed to concentrate the energy in the direction of the target. This result is accomplished by providing shaped electrodes that tend to produce initially a cone-shaped plasma. Referring to FIGURE 1, there is shown one form of the invention which may be incorporated with a conventional jet bit. More particularly, the electrode assembly is secured to the lower end of a drill string. The electrode assembly consists of tubular center electrode 11 and an outer or ground electrode 12. The tubular electrode terminates a cone-shaped lower end 13 and is provided with a central bore 14 that serves to conduct the jet fluid to the bottom
of the bit. The tubular center electrode serves as the discharge jet and creates a high-velocity jet to drill soft materials. The central electrode is hermetically or encapsulated in a dielectric material which may be conventional molded plastic or other suitable dielectric material. The upper end of the outer electrode is provided with male threads in order that the assembly may be secured to the lower end of the drill string. The diameter of the central electrode is adjacent to the outer periphery of the conical surface of the central electrode. The lower end or tip of the ground electrode 22 extends below the lower end of the insulator shown in FIGURE 1. Conductors 18 and 19 are provided for coupling the two electrodes to the remainder of the circuitry, not shown. Of course, the outer electrode 12 can be coupled to the drill string 10; the drill string could act as a ground for the circuitry.

The above shaped spark source is operated by applying a suitable voltage to the central electrode. This can be accomplished by discharging a storage capacitor across the electrodes. The discharge of the voltage will cause a spark to be initiated between the electrodes and the conducting drilling fluid connected to ground electrode 12. The spark, of course, ionizes a portion of the fluid between the surrounding electrodes and produces a high-temperature, high-velocity plasma which generates a converging shock wave (shown by lines 9) that tends to converge along the axis of the cone, producing a high-speed jet of fluid. The resulting jet of fluid is accelerated by the converging shock wave and directed towards the bottom of the borehole. Thus, the maximum amount of energy of the plasma is directed towards the bottom of the borehole.

Referring now to FIGURE 2 there is shown a modified form of the invention which is particularly adapted for use with a jet bit. More particularly, the modified form uses a tubular central electrode 20 whose lower end terminates at the apex of the conical surfaces 22 of the insulator 21. A tubular outer electrode 23 is provided with male threads for attaching the assembly to the bit or drill string, e.g., via the bit-body. The lower ends of the outer electrode 23 terminates adjacent the periphery of the conical surface 22. A conductor 24 is disposed in the insulator and couples the electrode 20 to circuitry not shown.

The modified electrode assembly can be operated as a jet bit by jetting a suitable fluid through the center electrode when the drill is operating in soft material. It can also be operated as a spark drill in hard material by discharging a suitable voltage between the electrodes or as a combination spark and jet drill. For use in fresh water of low conductivity the lower portion 39 of insulator 21 may be made of a cation exchange resin such as Dowex 50W, sold by Dow Chemical Company of Midland, Mich., dispersed in a plastic such as nylon. Such a material has a very low bulk conductivity, but a surface exposed to water acquires a relatively high conductivity which provides a conducting path to initiate the discharge.

Referring now to FIGURE 3, there is shown the electrode assembly combined with a conventional roller cone bit. More particularly, there is shown a borehole 30 having a drill string 31 extending downwards therein. The bottom end of the drill string is coupled to a tool section 32 with the roller cone bit 33 being secured to the lower end of the tool section. A shaped electrode assembly similar to that described in FIGURE 2 is secured to the center of the drill bit assembly.

The tool section 32 contains the equipment for operating the shaped spark electrode assembly and may include a mud turbine 36 and suitable pressure controls 35. The pressure controls are designed to bypass the mud turbine when the shaped spark source is not used and to pass the mud through the turbine when the spark source is operated. The mud turbine is coupled to a generator 37 that provides a suitable voltage for the charging circuits 38. The charging circuits in turn are coupled to the electrode assembly and include suitable controls for controlling the operation of the shaped spark source.

The combination of the roller cone bit and shaped spark source provides a drill that is capable of boring a true gauge hole in formations. More particularly, the roller cones will insure the true gauge of the hole while the shaped spark discharge will supply the high power required to break hard formations. Thus, the combination provides an efficient means for drilling earth formations. Of course, the roller cones may be used to drill earth formations without resorting to the use of a spark discharge.

From the above description it is appreciated that this invention provides a means for increasing the effectiveness of a spark type drill without increasing the power supplied to the drill. This is achieved by providing a cone-shaped end on the electrode assembly to generate a large shock wave and direct it towards the desired target. By concentrating the shock wave instead of allowing it to disperse in the form of a radial shock wave, the efficiency of the discharge is improved. More than one spark can be disposed at the end of a drill string or on one bit. Such a spark could be operated simultaneously or sequentially in various combinations.

I claim as my invention:

1. An electrode assembly for a spark discharge for concentrating the spark discharge along an axis, said assembly comprising:
a first electrode, said first electrode being disposed along said axis;
a second electrode, said second electrode being displaced from said first electrode;
an insulator, said insulator surrounding said first electrode;
and
one of said first electrode and said insulator having a conical shape with the axis of the cone being coaxial with said axis.

2. The assembly of claim 1 wherein said first electrode terminates in a conical-shaped end.

3. The assembly of claim 1 wherein said first electrode is provided with a fluid passage through the center thereof.

4. The assembly of claim 3 wherein said second electrode surrounds said first electrode with said insulator being disposed between said first and second electrodes, the portion of said insulator adjacent said electrodes having conical shape, the end of said second electrode being adjacent the outer periphery of the insulator.

5. An apparatus for drilling a borehole comprising:
a drill string;
a tool section attached to the lower end of said drill string;
a drill bit secured to the lower end of the tool section; and
a shaped spark discharge disposed on said drill bit to direct the spark discharge downwardly, said spark discharge comprising a central electrode surrounded by an insulator and an outer electrode, the lower end of one of said electrodes and insulator having a recessed conical shape.

6. The apparatus of claim 5 wherein said insulator is formed of a material that exhibits a relatively greater conductivity in contact with water.

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