PLASMA DRILLING

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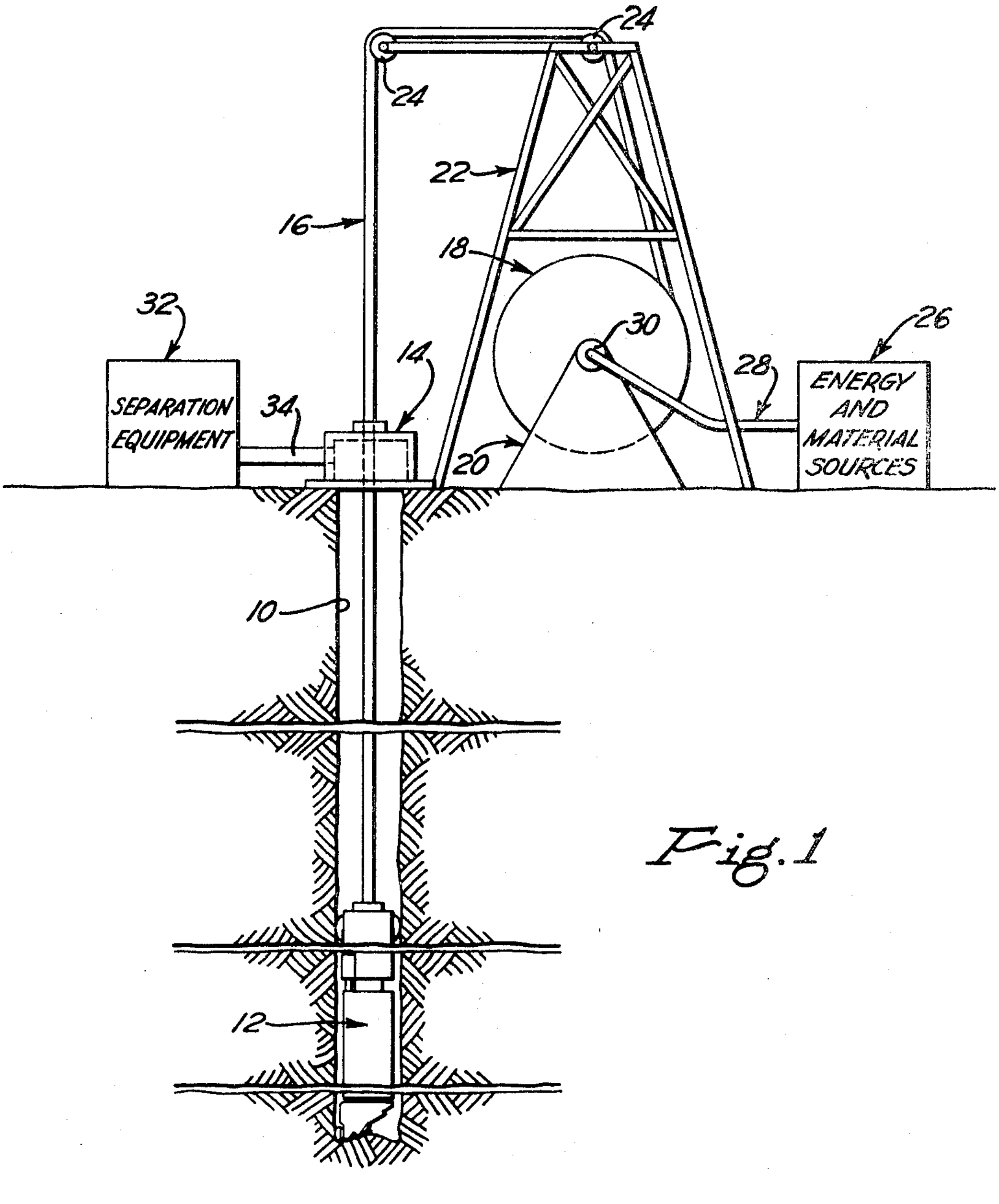

Fig. 1

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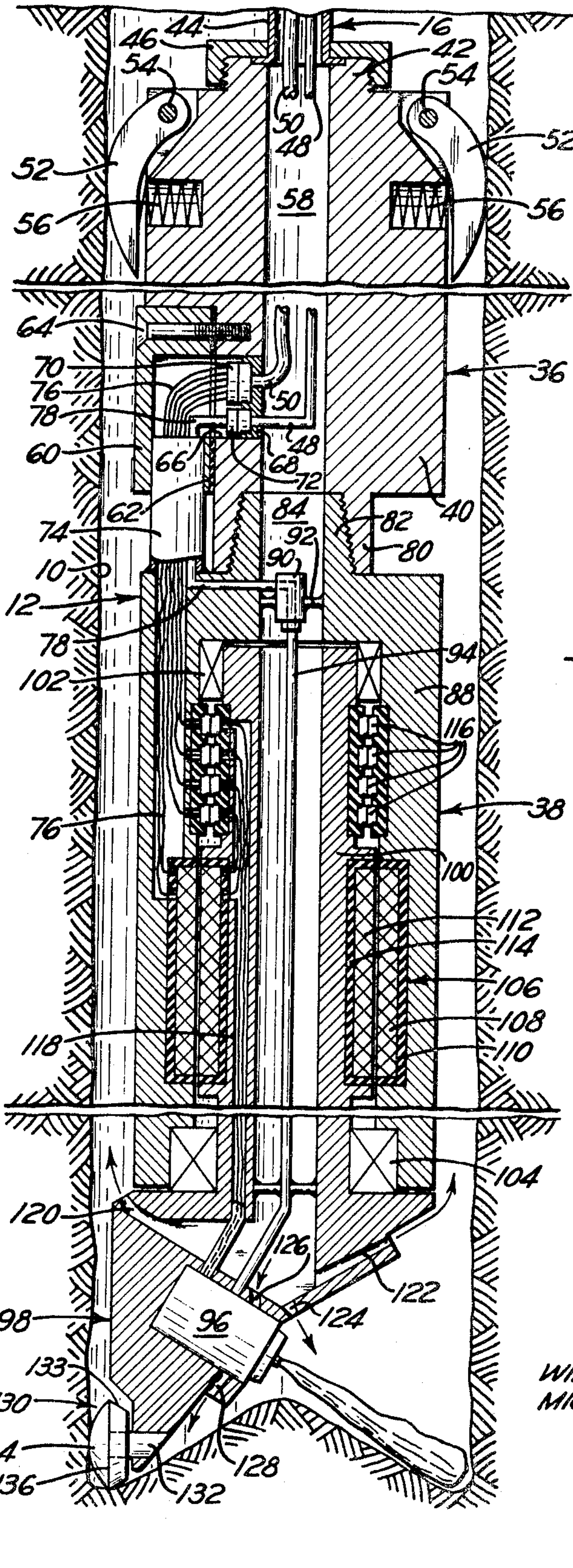

Fig. 2

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PLASMA DRILLING

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ABSTRACT OF THE DISCLOSURE

Method and apparatus for drilling wells in the earth utilizing a stream of disassociated gas (plasma) a reelable tubing to achieve wire line-like operation, and adding fluxing agents to melt at the bottom of the hole to automatically case the well as it is drilled. The plasma generator is mounted on the drill so that the stream of plasma crosses the axis to cover the entire bottom of the hole as the drill rotates.

This invention relates generally to the art of drilling wells in the earth, especially for the recovery of hydrocarbon deposits, and more particularly is directed to methods and apparatus for drilling such wells utilizing plasma.

As used herein, the term "plasma" shall mean a stream of gas whose molecules have been disassociated and ionized. A plasma generator therefore is a device that produces such plasma. As is well known, when plasma is directed at a target, the gas will reassociate, and will produce tremendous quantities of heat at very high temperatures, temperatures on the order of 60,000° F. can be achieved. The present invention uses a plasma generator to drill wells.

The plasma drilling method of the present invention is not to be confused with and is materially different from the so-called "electric arc" types of drilling. In said electric arc drilling means are provided to create an electric arc at the bottom of the borehole, and the heat of the arc itself is utilized to crack and spall the formation. The heat is therefore very close to the electrodes and consumes them rapidly. The electric arc method also avoids melting of the formation because the melted rock would foul the equipment. In the present invention, the heat is transmitted by the plasma which releases its heat upon re-association, and the object is to melt the rock. The melted formation in the present invention will not foul the equipment because of the provision of both the stream of plasma which itself keeps the melted rock away from the plasma torch, and secondly, the stream of scourging gas which serves the same purpose, in addition to serving the purposes of cooling the plasma generator and as a carrier to bring the melted and aerated rock to the surface. Since the heat is released at points spaced from the generator, the electrodes are not so rapidly consumed.

Another feature of the present invention is that the drill head rotates while drilling the hole. Rotation of the drill head achieves advantages over both electric arc and plasma type drills wherein the torch or generator is oscillated. In such oscillating head drills, the method is inherently discontinuous and therefore less efficient. If the arc of oscillation is less than 360° then an arcuate area will exist that will not be positively drilled. If the arc of oscillation is more than 360° then the overlap region will be drilled twice which is a waste of time and which causes lost motion of the drill head. Thus, by rotating instead of oscillating the drill head, the net effect is that the drill cuts faster and smoother without any dead spots, which results in smaller and more easily transported "cuttings."

The method of the present invention is also materially different from and has advantages over those types of drill bits wherein a flame is used to remove the formation. In the present invention, under normal operating conditions, that is, in the absence of combustible fluids in the formation, there will be no flame. In such prior flame drills, there is a problem of keeping the flame away from the torch to prevent it from destroying the torch, there is a problem both technologically and economically in supplying fuel to the torch, and there is a problem of corrosion since the products of combustion are corrosive to the drill. The present invention avoids all of these problems since there is no fuel supply, since the gas re-associates at zones spaced from the generator, and since there is no combustion and therefore no products of combustion.

One problem common to virtually all kinds of drilling methods presently in use is that a "drill string," comprising long lengths of heavy walled pipe, is utilized to both transmit energy to the drill bit at the bottom of the hole, and to transmit cooling and chip carrier fluids, known as "drilling mud," to the bottom of the hole. Such drill strings are in themselves expensive, require large amounts of energy to turn, and require considerable time to periodically remove from the hole for purposes of changing the bit, and for other purposes.

Another problem present in conventional types of drilling is that the sides of the borehole are left unprotected as depth increases. This is often a problem when unconsolidated formations, such as loose sand or the like, are encountered. The problem is solved, conventionally, by casing the well, which comprises removing the drill string from the well, inserting relatively large diameter pipe into the well to the zone it is desired to case off, and then filling the space between the outside of the pipe and the side of the borehole with cement, to thereby seal off the troublesome zone. Casing is an expensive and time consuming procedure. The present invention eliminates or at least substantially reduces the amount of casing that must be done by means of the inclusion of fluxing agents into the scourging or ionizing gas. When such fluxing agents are exposed to the very high temperature which will be generated at the bottom of the borehole during drilling, they will melt, and in effect, a lining for the side of the borehole will be created as a by-product of the drilling operation and simultaneously therewith. The particular flux used will depend upon the nature of the formation being drilled.

In the accompanying drawing forming a part of this disclosure: FIG. 1 is a diagrammatic vertical cross-sectional view of the apparatus of the invention showing the plasma drill of the invention drilling a well; and FIG. 2 is a longitudinal cross-sectional view through the drill of the invention.

Referring to FIG. 1, there is shown a borehole **10** which is being drilled by plasma drill **12**. The surface equipment includes a well head **14**. It will be understood that well head **14** is diagrammatic only, and will include but does not show conventional safety equipment such as blow-out preventers, and other conventional equipment well known to those skilled in this art. Drill **12** is connected to the surface by a composite cable **16** which connects the drill to a reel **18** mounted on a reel support **20**. Preferably, reel and reel support **18** and **20** are mounted close to and may be a part of a derrick assembly **22** which includes guide rollers **24** which guide cable **16** and drill **12** in vertical motion in the well **10**.

As will appear more clearly in the detailed description of drill **12** below, the drilling method of the invention requires that ionizing gas, scourging air, electricity for the electrodes within the plasma generator, and electricity to turn the plasma generator be supplied through cable **16** from the surface to the drill **12**. In some cases, it will also be desirable to supply fluxing agents through the cable to the drill.

Reference numeral **26** designates a "black box" labeled "Energy and Materials Sources" in FIG. 1. This black box indicates the various pieces of equipment that supply the above energies and materials to cable **16** for delivery to drill **12**. It will be understood that any suitable means may be used for the supply functions. For example, the ionizing gas may be supplied by a pump. The two separate electrical currents may be supplied by generators on the drill site, or by connection to utility company service lines in the area if such are available. The scourging air may be supplied by tank trucks of compressed air, on-site compressors, or the like, and means such as a gravity feed hopper, aspirator, screw feeder, or the like, may be used to supply the fluxing agents in powdered form. Supply conduits, generally indicated by conduit **28**, connect the energy and material sources to the hub **30** of reel **18**, and various electrical brush and rotating valve assemblies, not shown, are provided within hub **30** to transmit the energy and materials to the various parts of cable **16**, as will be described more clearly below.

Reference numeral **32** designates a "black box" labeled "Separation Equipment" in FIG. 1. This black box indicates equipment to separate the formation material removed by drill **12**, equipment to detect any fluids such as hydrocarbon liquids or gases that may be included in such material, and equipment to vent the cleansed air after the above matter is removed from it. It will also include equipment to flare gas if gas is used as the scourging fluid. Separation equipment **32** serves the function of the mud tanks, pumps, shale shakers, and the like used in conventional rotary drilling. The formation removed by the drill **12** will be returned to the surface in the form of a crystallized froth or as solidified aerated globules, and these "cuttings" may be removed from the air by appropriate equipment such as screens, cyclones, settling chambers, or the like. A conduit **34** connects the separation equipment **32** to well head **14** and communicates the annulus between the borehole **10** and the cable **16** with the separation equipment. As in conventional drilling, the energy and materials are supplied through the cable, analogous to the drill string, and returned via the annulus.

Referring to FIG. 2, drill **12** is essentially a two-part structure comprising an upper member **36** and a lower member **38**. Upper member **36** serves as a weight and stabilizing bar, and as an energy and material distribution point for the drill.

Upper member **36** comprises a main body member **40** formed with suitable connection means, such as a threaded nipple **42**, to receive the lower end of the outside wall **44** of cable **16**. A collar member **46** is threaded on nipple **42** and holds the lower end of the outside wall **44** of cable **16** onto the drill **12**. The connection means **42, 46** is exemplary only, and it will be understood that various means are available to attach the cable wall to the upper end of the drill. The outside wall of cable **16** may be formed of any suitable material which will bear the weight of the drill, and which will allow itself to be reeled. Within outside wall **44** cable **16** includes a relatively small diameter conduit **48** which carries the ionizing gas, and a second small diameter conduit **50** which carries the electrical leads. The I.D. of outside wall **44** is considerably larger than the sum of the diameters of conduits **48** and **50**, and the relatively large annulus inside wall **44** is used to transmit the scourging fluid, preferably air, to the drill head, as will be explained below. If desired, the conduits **48** and **50** could be fabricated integrally with outside wall **44**. Gas carrying conduit **48** could be a flexible metal tubing, and electrical lead carrying conduit **50** could be of insulated, multi-wire construction.

Since plasma generators are essentially high amperage/low voltage devices, and since the required electrical lead diameter is a function of amperage, it may be desirable to include a downhole transformer in upper member **36**, along with associated rectifying equipment to convert the energy to D.C. This equipment is not shown in the drawing, but it may be easily provided in upper member **36**, if it should be desired. It is desirable to work with relatively thin electrical leads as far as possible, from the economy viewpoint, and from the viewpoint of keeping the total size of the reelable cable **16** as small as possible.

Main body member **40** serves as a weighting member to maintain the drill stable in the hole and to aid it in its downward movement as it drills the hole. The upper member **36** is shown broken to indicate that any length of member **40** could be provided dependent upon the amount of weight desired, and, as will be explained below, the upper member **36** can be readily changed during the drilling of a hole. Additional means are provided to stabilize the drill in the hole. To this end, a pair of spring loaded arms **52** are hinged to the top of the body member as at **54** and are biased outwardly against the sides of the borehole **10** by springs **56**. As will be understood by those skilled in this art, more than two arms **52** could be provided. The arms **52** serve to centralize the drill in the hole, and other types of centralizers such as bow springs could be provided in their place.

Upper member **36** is provided with a longitudinal central opening **58** through which the conduits **48** and **50** pass, and which is in communication with the inside of cable **16**. Thus, longitudinal opening **58** serves as a scourging gas conduit to deliver the scourging gas to the drill.

Means are provided to permit quick connection and disconnection of gas and electrical conduits **48** and **50** between upper member **36** and lower drill member **38**. To this end, a cover plate **60** is provided at the lower end and at one side of upper member **38**. Suitable means such as gasket **62** and bolts **64** are provided to permit ready removal of the cover plate. Under cover plate **60**, body member **40** is formed with a radial opening **66** in which is mounted a terminal block **68** in which are removably mounted a quick disconnect coupling **70** for the electrical conduit **50** and a quick disconnect coupling **72** for the gas conduit **48**. Lower member or drill **38** includes a protective sheath **74** which extends into a suitably formed opening in cover plate **60** and through which passes electrical leads **76** and gas lead **78** which lead to the quick disconnect couplings **70** and **72**, respectively. At its extreme lower end, body member **40** is formed with a conventional drill pipe "box" or female pipe thread connection **80**, which cooperates with a "pin" or male connection **82** on the upper end of drill **38**. Suitable conventional sealing means, not shown, may be provided between pin and box connection **80, 82**.

Thus, the upper weighting and stabilizing member **36** can be asembled or dissembled from the drill, or a heavier or lighter member can be provided, by removing cover plate **60**, breaking quick disconnect couplings **70** and **72**, and breaking thread connections **80, 82**.

Drill **38** comprises an axial longitudinal chamber **84**, which is in tandem with opening **58** to provide a continuous passageway from the inside of cable **16** to the drill head through the drill and the upper member. After its passage through sheath **74** gas lead **78** passes through a suitable radial opening **86** in the body of drill **38** to a rotary seal device **90** positioned in air chamber **84**. Rotary seal **90** is held in place by any suitable means such as struts **92**. A rotating gas delivery pipe **94** is connected to the lower end of rotary seal **90** and delivers the ionizing gas to the plasma generator **96** located in the rotary drill head **98**, as will be described below.

Means are provided to rotatably mount and to cause rotation of rotary drill head **98** with respect to drill body **88**. To this end drill body **88** is of a generally elongated U-shaped configuration in cross section to receive a stem portion **100** of rotating drill head **98**. Upper bearing **102** and lower bearing **104**, of conventional anti-frictional roller or other type, is provided between the drill body **88** and drill head stem **100**. Drill **38** includes a motor **106** which drives the drill head. The stator **108** of motor **106** is mounted by means of suitable electrical insulation **110** in drill body **88**, and the rotor **112** with suitable insulation **114** is mounted in stem portion **100** in juxtaposition to the stator. Electrical energy is supplied to stator **108** by a pair of the electrical leads **76** after they pass through sheath **74**. Four sets of electrical brushes and commutator assemblies **116** are provided between body **88** and stem portion **100**. Two brush assemblies **116** are used to transmit electrical energy delivered by two of the leads **76** to rotor **112** of motor **106**. The remaining two brush assemblies **116** pass through a conduit **118** in rotating head **98** and deliver electrical energy to the plasma generator **96**.

As shown, motor **106** comprises only one rotor/stator stage. It will be understood that more than one such stage, with the appropriate brush assemblies **116**, may be provided to provide a more powerful motor. The drill is shown broken between lower bearing **104** and motor **106** to indicate the inclusion of additional electrical motor stages, if required.

As explained above, the scourging gas passing through cable **16** and passageways **58** and **84** to the bottom of the borehole serves several important functions, i.e., cooling of the plasma generator **96**, as a vehicle to carry the melted formation particles away, and to aid in directing the stream of plasma away from the generator. Therefore, the lower end of rotating drill head **98** is formed with several different passageways each of which receives some of the scourging gas and which serve these various purposes. Passageways **120** and **122** are directed upwardly from the generator and stream of plasma and serve primarily to push the "cuttings" up the annulus to the surface. Passageway **124** is directed downwardly and tangentially at a small angle to the direction of the plasma stream and serves primarily to direct the plasma stream away from the generator. Passageway **126** is connected to the internal cooling passageways within the generator, and serves primarily to cool the generator. A passageway **128** exhausts the air supplied through passageway **126** and also serves to direct formation particles out towards the sides of the borehole. It will be understood that the passageways **122** through **128**, shown and described, are but representative of the various types of passageways and that several of each type of passageway may be provided.

The lower end of rotating head **98** is of triangular cross-section and includes the lowest part of the drill. At said lowest part an idler roller assembly **130** is provided which guides the rotational motion of the drill head. Roller assembly **130** comprises an axle **132** and an idler roller **133** which comprises a hemispherical end face **134**, joined to the body of the roller by a sharp edge **136**. Thus, the roller makes a sliding point contact with the side of the borehole on hemispherical portion **134**, and a rolling contact with the bottom of the borehole on edge **136**.

The plasma generator **96** is disposed at an angle and is directed downwardly with respect to the axis of the drill, and is positioned to one side of said axis with its exit orifice close to said axis, so that the stream of plasma will cross the axis and travel a distance greater than the transverse radious of the hole. The length of said stream is adjustable by adjusting certain parameters within the generator, such as throttling means for the ionizing gas and the physical configuration of exit orifices and the like, and is set so that the effective length of the stream will be such that a hole having the desired diameter will be produced. The bottom of the hole will therefore have a cone or hill-like configuration as shown.

By locating the plasma generator as described, the generator will drill across the axis of the hole, which results in accurate control of hole diameter. The generator may be adjusted and controlled, from the surface, by increases or decreases in one or both of the supply of ionizing gas or electrical power.

By so directing the plasma stream in combination with the inclusion of fluxing agents, which will melt and migrate towards the side of the borehole, the advantage of obtaining a self-casing borehole will be obtained. The finely powdered particles of fluxing agent in either the ionizing gas or scouring gas will melt, and when directed outwardly by the stream of plasma, as primarily by the passageways **124** and **126**, will coat the side of the borehole with a glass-like lining. The fluxing agents will be so finely powdered that they will not clog any of the passageways in the generator or the rotating drill head. Suitable materials for use as the fluxing agent include borax, feldspar, silicon oxides, or other suitable minerals, dependent upon the nature of the formation being drilled. The ionizing gas is preferably a diatomic inert gas such as argon, nitrogen, or suitable other gases or combinations of gases. The scourging gas is usually air, but in those cases where it is anticipated the hydrocarbon deposits will be in the form of natural gas, air is not desirable because of the explosion danger. In such wells, gas, methane or natural gas readily available in many oil fields, may be used as the scouring gas, or even the exhaust gases from the various engines on the drill site, properly treated to remove solids and corrosive agents, could be used as the scouring gas.

The intense heat generated by the re-association of the gas will melt the rock. The relatively large amount of scourging gas, air or methane or whatever is being used, added into the molten rock will cause the rock to froth trapping bubbles of this gas as well as bubbles of the re-associated gas as the rock cools, resulting in a light material which may be easily driven up the annulus. The molten froth will, because of its light weight and rapid motion, quickly give up its heat primarily to the surrounding formation, and will then be carried up to the surface and delivered to separation equipment **32**. The scourging gas will also help to cool the "cuttings."

We claim:

1. A method of drilling earth boreholes with plasma comprising the steps of rotatably mounting a plasma generator on a drill, holding the body of the drill stationary with respect to rotation about the axis of the drill, rotating the plasma generator about the axis of the drill, directing the stream of plasma produced by the plasma generator from one side of the axis of the drill at an angle to said axis acros said axis and over the entire bottom of the borehole during each revolution of the generator, and lowering the drill as the drill creates the borehole.

2. A method of drilling earth boreholes with plasma comprising the steps of rotatably mounting a plasma generator on an axially rotatable drill to direct the stream of plasma produced by the plasma generator from one side of the axis of the drill at an angle to said axis across said axis and over the entire bottom of the borehole during each revolution of the generator, mounting said drill on a reelable cable, supplying electrical energy to said plasma generator through said cable, supplying electrical energy to a motor in said drill through said cable to cause said plasma generator to rotate with respect to said drill, supplying a disassociatable gas to said plasma generator, supplying a stream of scourging gas to said drill through said cable, and lowering said drill on said reelable cable as said drill creates the borehole.

3. The method of claim **2**, and supplying finely powdered fluxing material to said scourging gas.

4. The method of claim **2**, and supplying finely powdered fluxing material to said disassociatable gas.

5. Apparatus for drilling earth boreholes comprising a drill, a plasma generator mounted on said drill, means to cause rotation of said generator about the axis of said drill, cable means connected to the upper end of said drill, means to reel and unreel said cable means from the surface to raise or lower said drill in the borehole, and said plasma generator being mounted on one side of said drill with respect to the axis thereof and disposed at an angle with respect to the axis thereof and with the plasma outlet end of said generator close to the axis thereof, whereby the stream of plasma issuing from said generator will flow across the axis of said drill.

6. The apparatus of claim **5**, said means causing rotation of said generator about the axis of said drill comprising an electrical motor, said motor comprising a motor stator mounted on a body portion of said drill, means to hold said body portion stationary with respect to rotation about the axis of said drill, said drill comprising a stem portion rotatably mounted within said body portion of said drill, said drill comprising a drill head portion forming part of said drill stem portion, said motor comprising a motor rotor mounted on said drill stem portion in juxtaposition to said motor stator, said plasma generator being mounted on said drill head portion, and means to supply electrical energy to said motor rotor and said motor stator from the surface through said cable means.

7. The apparatus of claim **5**, said drill comprising a body portion, means to hold said drill body portion stationary with respect to rotation about the axis of said drill, said drill comprising a rotating portion carrying said plasma generator, and motor means disposed on said stationary portion and said rotating portion to power said rotating portion with respect to said stationary portion.

8. The apparatus of claim **5**, said drill comprising an upper member and a lower member, means to removably join said upper member to said lower member, said upper member and said lower member being formed with axial passageways in communication with each other and in communication with the central opening within said cable means, whereby a flow of scourging gas may be supplied from the surface through said cable means and the passageways in the portions of said drill to said generator and the bottom of the borehole; said upper member comprising a weighting and stabilizing member, and said lower member comprising a drilling member.

9. The apparatus of claim **5**, and cable means including means to supply a flow of disasociatable gas from the surface to said plasma generator, said cable means including means to supply electrical energy from the surface to said plasma generator, and said cable means including means to supply a flow of scourging gas from the surface to the vicinity of and to said plasma generator.

10. The apparatus of claim **9**, said drill comprising an upper weighting and stabilizing member and a lower drilling member, said upper and lower members being formed with communicating axial passageways which also communicate the space within said cable means with the bottom of said borehole and said plasma generator, said upper member comprising quick disconnect means adapted to quickly connect and disconnect said electrical energy supply means and said disassociatable gas supply means, said scourging gas supply means comprising said communicating passageways within said upper and lower members, and means to connect or disconnect said upper and lower members, whereby said upper and lower members may be readily separated from each other for replacement of either of said upper and lower members.

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