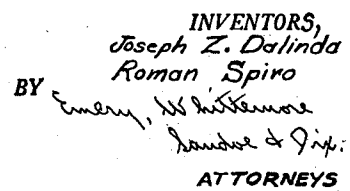


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METHOD AND APPARATUS FOR DRILLING WITH DISSOCIATED GAS

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Fig. 8

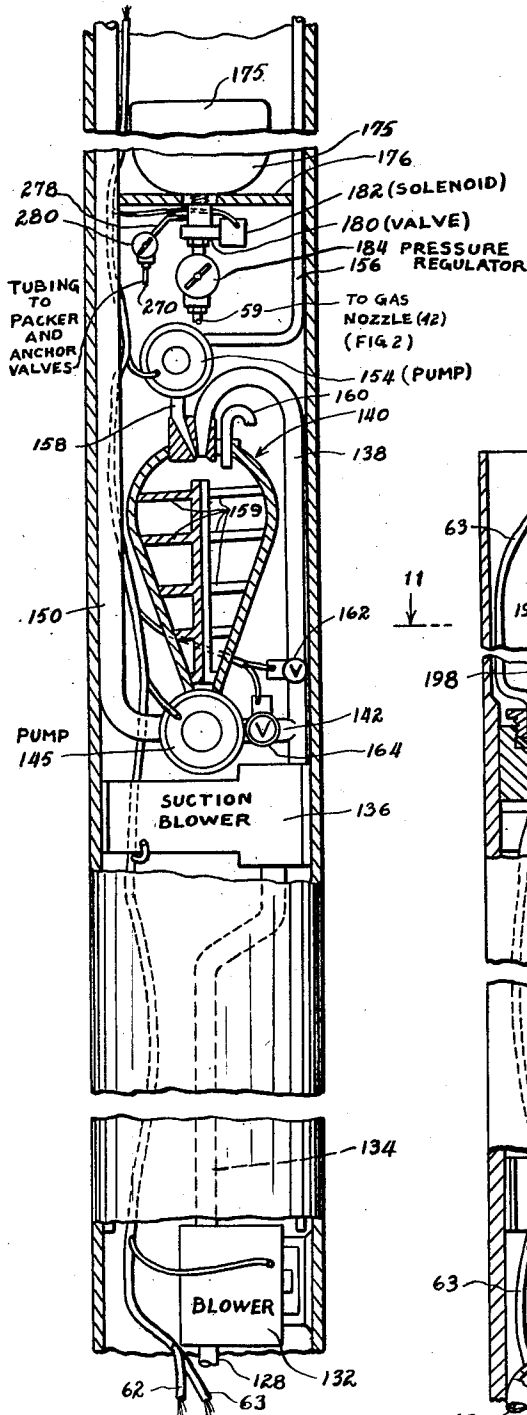
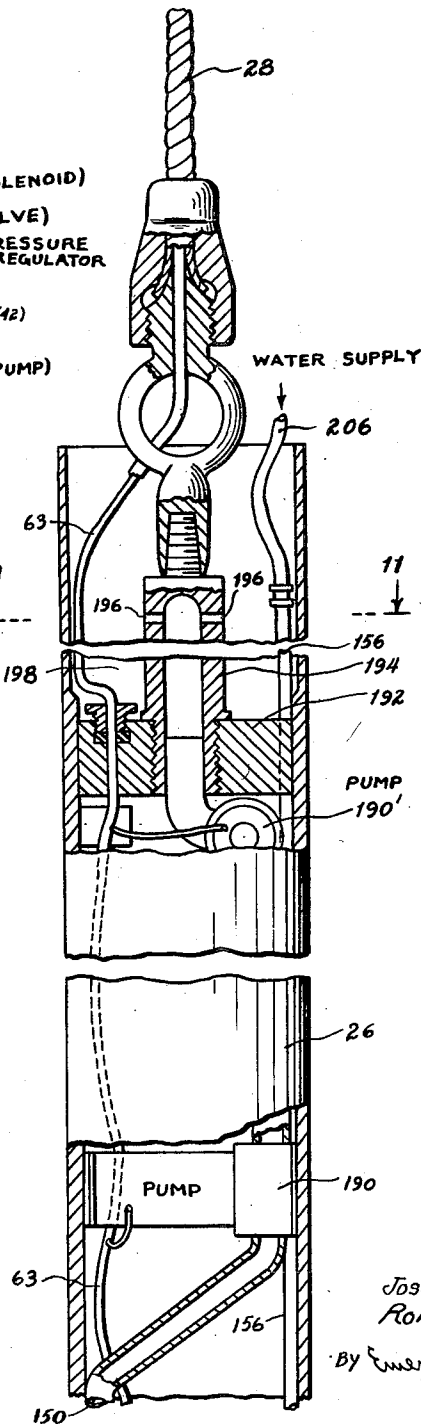


Fig. 9

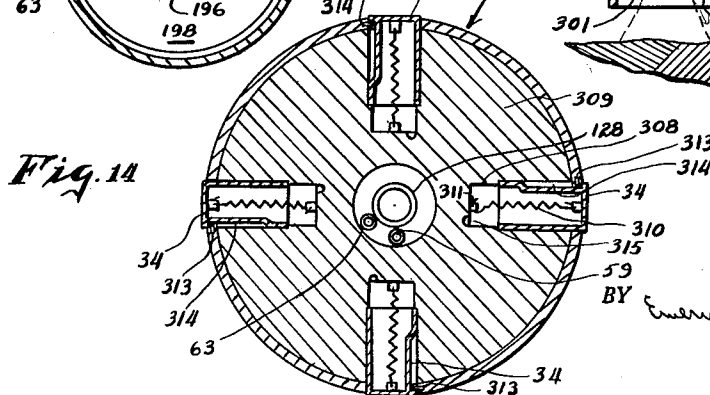
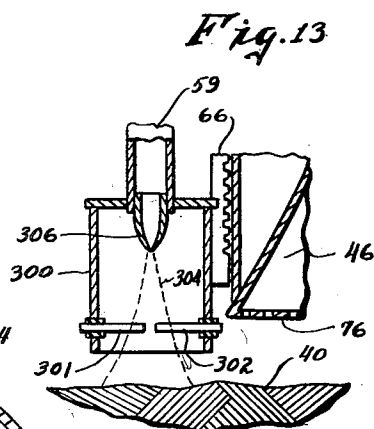
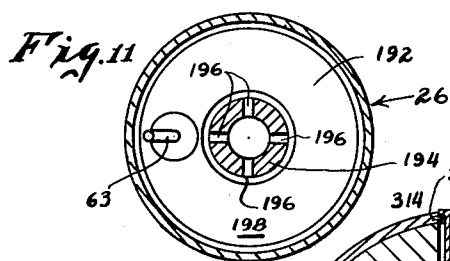
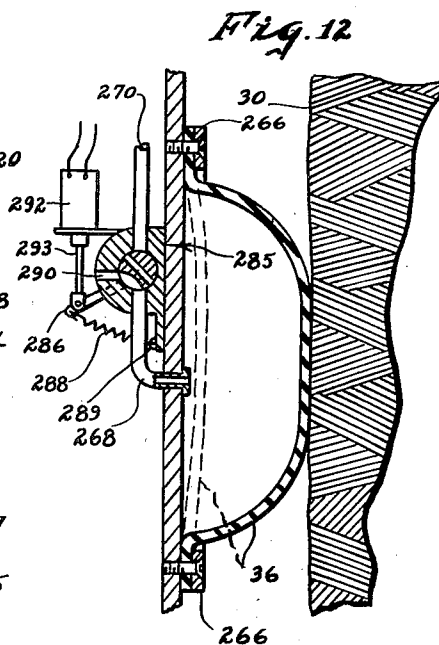


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Filed July 13, 1956

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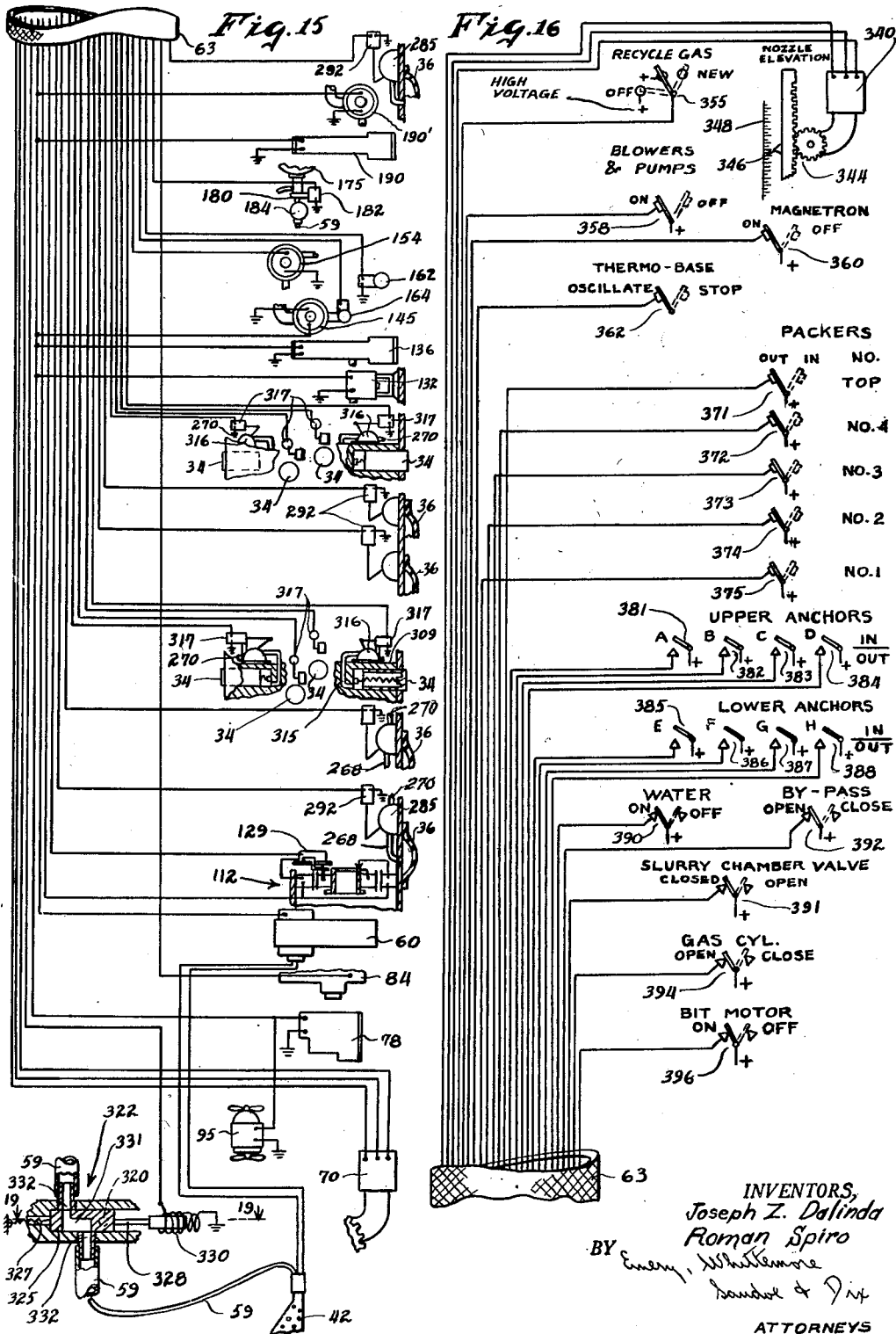
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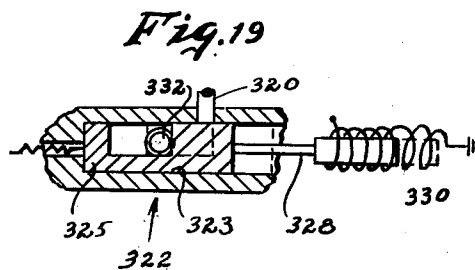
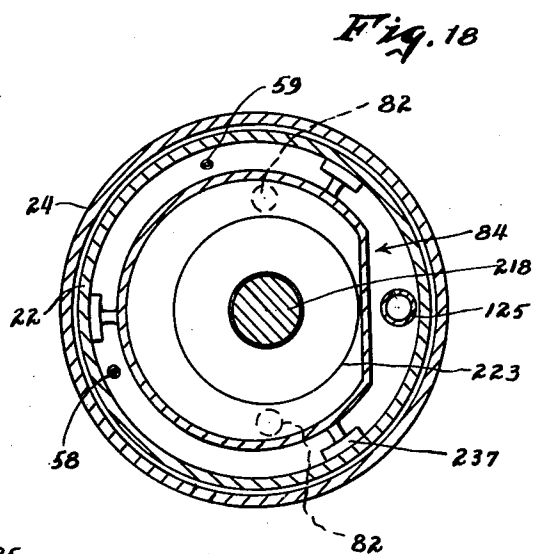
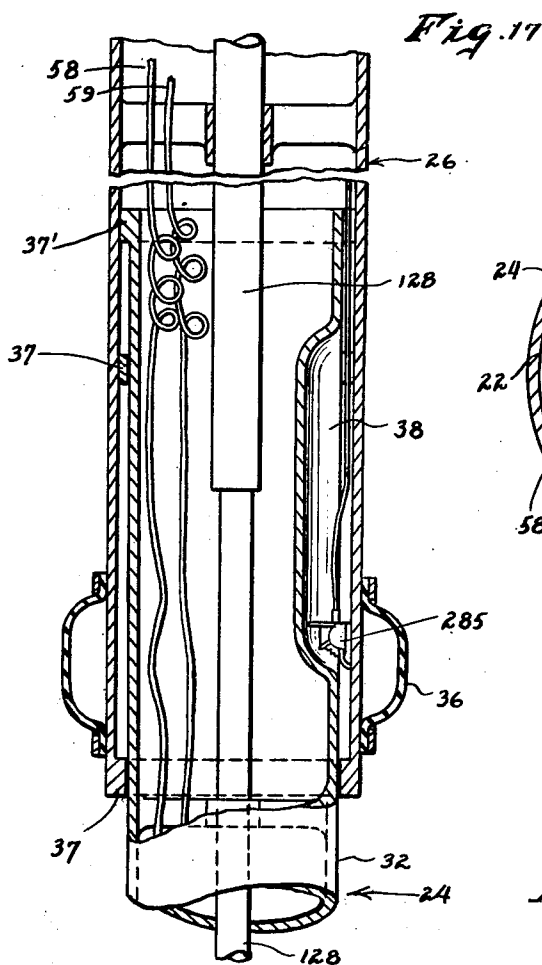
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2,816,735

METHOD AND APPARATUS FOR DRILLING WITH DISSOCIATED GAS

Filed July 13, 1956

6 Sheets-Sheet 6



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2,816,735

METHOD AND APPARATUS FOR DRILLING WITH DISSOCIATED GAS

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Application July 13, 1956, Serial No. 597,823

29 Claims. (Cl. 255—1.8)

This invention relates to apparatus and methods for drilling, and more especially to thermal drilling in which heat is applied to localized areas to cause such steep temperature gradients that differential expansion causes spalling of the rock or other lithologic formations in which the drilling is performed.

It is an object of the invention to provide improved apparatus and methods for disintegrating, penetrating and removing lithologic formations for oil wells, mining, blast holes, or any other purpose where it is necessary to penetrate the earth for substantial distances, and more especially where it is necessary to penetrate through hard rock.

Another object of the invention is to provide apparatus and methods for penetrating rock or other lithologic formations by means of heat generated by the reassociation of dissociated gas. The generation of heat by the reassociation of gas has a number of important advantages over the use of combustion flames for drilling operations. One advantage is that the heat is generated over a more localized and defined region as compared with the billowing flames which result from combustion and from the relatively slow rates of flame propagation through a combustible mixture of gases. Another essential advantage of this invention over flame heating is that the heat of highest temperature is developed on impinging rock and not at the starting point, as in the case of the flame. A more localized heat release results in steeper temperature gradients and more intense thermal stresses for spalling the lithologic formation.

Other advantages are the absence of explosive gas mixtures in the end of a bore; the fact that the gas after reassociation can again be dissociated and the same gas used over again; more accurate control of the area to which heat is applied at any given instant; and the greater facility with which the heat can be controlled from a remote location at the head of the bore.

Another object of the invention is to provide a thermal drilling machine and method in which the operations are performed by generating heat at the face of the bore and in an unflooded chamber. The expression "unflooded chamber" is used herein to designate a space immediately adjacent to the face of the bore which is substantially filled with gas and in which operations are carried out without requiring the use of quenching water, though some water will on occasions leak into the chamber through the face or walls of the bore. Provision is made for removal of this water by the evacuation channel and by vaporization so that the stream of dissociated gas could impinge the working surface.

One feature of the invention relates to the evacuation of cuttings or spallings from the face of the bore, and to means for removing them from the drilling machine.

Another advantage of the invention is that the evacuation of dry cuttings entrained in a stream of gas from the region immediately in front of the face of the bore makes practical the sampling of gas for hydrocarbons at the end of the bore, and as a continuous operation,

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so that the operators of the drilling machine, when drilling for oil, will be advised promptly of the indication of oil or gas in the vicinity of the bore. However, the cuttings could be examined for a number of other purposes, especially in mining.

This application is a continuation in part of the patent application filed by Joseph Z. Dalinda, Edwin Langberg, and Roman Spiro, Serial Number 230,342, filed June 7, 1951, and now abandoned.

Other objects, features and advantages of the invention will appear or be pointed out as the description proceeds.

In the drawing, forming a part hereof, in which like reference characters indicate corresponding parts in all the views;

Figure 1 is a sectional view through a bore in the earth and showing the drilling machine of this invention in operative position;

Figure 2 is a greatly enlarged, diagrammatic sectional view of the lower part of the drilling machine shown in Figure 1;

Figures 3-7 are sectional views taken on the lines 3-3 to 7-7, respectively, in Figure 2;

Figure 8 is a vertical sectional view through a part of the drilling machine above the thermo-base;

Figure 9 is a diagrammatic, vertical sectional view through a portion of the drilling machine above the part shown in Figure 2;

Figure 10 is a view similar to Figures 2 and 9, but showing the upper end of the drilling machine of Figure 1;

Figure 11 is a sectional view taken on the line 11-11 of Figure 9;

Figure 12 is a diagrammatic, vertical sectional view showing a modified construction of the apparatus for directing dissociated gas against the face of the bore;

Figure 13 is a sectional view through one of the packers shown in Figure 1;

Figure 14 is an enlarged sectional view on the line 14-14 of Figure 1;

Figure 15 is a wiring diagram for the apparatus shown in the other figures;

Figure 16 is a continuation of the wiring diagram of Figure 15 to control means at the head of the bore;

Figure 17 is a vertical sectional view showing the way in which the middle section of the housing telescopes into the upper section;

Figure 18 is a sectional view taken on the line 18-18 of Figure 10; and

Figure 19 is an enlarged sectional view taken on the line 19-19 of Figure 15.

Figure 1 shows a drilling machine 20 comprising a housing which is made in three sections including a bottom section 22, which will be referred to herein as the "thermo-base," a middle section 24 by which the thermo base 22 is carried and with respect to which the thermo-base 22 has oscillating movement about the longitudinal axis of the housing.

The drilling machine housing also has an upper section 26 which supports the thermo-base 22 and middle section 24, and which is itself supported by a cable 28 leading to the top of a bore 30 in which the drilling machine is located.

The upper end of the middle section 24 is of reduced diameter along a portion 32 of its length; and this reduced-diameter portion 32 fits into the lower end of the upper section 26 of the housing to hold the sections 24 and 26 together. This construction permits telescopic movement of the sections 24 and 26, and will be described in connection with Figure 17. The sections 24 and 26 of the housing have anchors 34 which project against the sides of the bore to prevent rotation of these sections 24 and 26 in the bore when the thermo-base 22 is being

oscillated during a drilling operation. There are packing rings 36 at spaced locations along the length of the drilling machine housing. These packing rings can be inflated to obtain firm contact with the sides of the bore 30 for the purpose of preventing water in the bore, above the drilling machine, from entering the chamber adjacent to the face of the bore. The construction and control of these packers 36 will be explained fully in connection with Figure 12. For the present it is sufficient to understand that the packers 36 are deflated to permit relative movement of the drilling machine lengthwise of the bore and they are inflated when necessary to provide a seal between the drilling machine housing and the side of the bore so that water cannot pass downwardly along the outside of the housing.

Figure 17 shows the construction by which the reduced diameter end 32, of the middle section 24, slides in the upper section 26. There are bearing rings 37 secured to the inside wall of the upper section 26 of the housing at axially spaced locations along the housing. The reduced diameter end 32 of the middle section 26 slides axially in these bearing rings 37. Another ring 37' attached to the upper end of the middle section 24 limits the extreme downward movement of the middle section with respect to the upper section 26.

The reduced diameter end 32 of the middle section 24 is cylindrical except for a depression 38 provided at one side to leave clearance for the valve and working fluid supply line which operates the packer 36.

The pipe 128 through which cuttings are evacuated from the bottom of the bore, extends axially through the sections 24 and 26; and the portions of the pipe 128 which are attached to the respective sections 24 and 26 telescope so as to compensate for the axial movement of these sections with respect to one another.

The conductor cable and hose which extend through the sections 24 and 26, and which are flexible, merely accumulate slack during the upward movement of the middle section 24 with respect to the upper section 26. These parts will be described as the description continues.

Figure 1 shows the lower end of the thermo-base confronting an end face 40 of the bore 30. There is a nozzle 42 at one side of the thermo-base 22 in position to direct a divergent stream of dissociated gas against the face of the bore. This stream is indicated by the dotted lines 44 in Figure 1.

In order to have the gas dissociate, a poly-atomic gas is used, such as hydrogen or carbon dioxide. Part of the gas is dissociated by passage through a high-frequency field; and when this gas impinges on the rock formation, the gas reassociates with the instantaneous liberation of the energy which was required to produce the dissociation. This instantaneous liberation of heat at the localized region of the rock surface produces a sudden thermal expansion of the rock and causes spalling of the rock surface.

On the other side of the thermo-base 22 there is an exhaust passage 46 through which cuttings from the face 40 are drawn into the housing of the thermo-base. A bit 48 is reciprocated toward and from the face 40 to break up spallings into small fragments for evacuation through the exhaust passage 46. The operation of the bit 48 will be explained more fully in connection with Figure 10. For the present it is sufficient to understand that it operates against the loose spallings or cuttings, which are disintegrated from the face 40 by the heat resulting from reassociation of the gas stream 44, in a manner similar to a pneumatic chisel; and the bit 48 fractures any spallings which are too large to pass through the exhaust passage 46.

The lower end of the thermo-base is shown in Figures 2-4. The nozzle 42 consists of two shells; an inner shell 51 and an outer shell 52. These shells are the opposite electrodes of a high frequency field, the windings of the field being indicated by the reference character 54. The

shells 51 and 52 are of rectangular cross section and they are held in spaced relation to one another, by spacer blocks 55 extending between the shells as shown in Figure 4, to provide a passage 56 through which the gas flows for discharge from the lower end of the nozzle as indicated by the dotted lines 44. The spacer blocks 55 are at different levels along the length of the passage 56 and of sufficient extent at the upper ends of the shells 51 and 52 to close the top of the passage 56 except for a gas inlet into the passage.

The high frequency power is supplied to the nozzle 42 through a conductor cable 58 from a source comprising a magnetron 60 located in the upper part of the thermo-base 22. Electric power is supplied to the magnetron 60 through a conductor 62 leading upwardly and enters a main conductor cable 63 through which the many conductors of the drilling machine connect with remote control means at the head of the bore.

A hose 59 supplies gas to the nozzle 42. This hose extends upwardly to a source of gas which will be explained in connection with Figure 8.

The gas stream indicated by the lines 44 diverges as it travels downwardly and the diameter of the bore made by the drilling machine is increased by adjusting the nozzle 42 upwardly into the dot-and-dash line position shown in Figure 2.

In order to guide the nozzle 42 in its vertical movement, there are blocks 64 on opposite sides of the nozzle in position to slide in guide grooves 65 formed in inside walls of a chamber provided in the thermo-base for receiving the nozzle 42. These grooves 65 are located on opposite sides of the nozzle 42, as best shown in Figure 4. At its inner end, the nozzle 42 is attached to a rack 66 which moves the nozzle up and down along the guide grooves 65. The upper end of the rack 66 extends into a recess 68 in the structure of the thermo-base above the level of the nozzle 42. The cable 58 and hose 59 extend through an opening in the structure of the thermo-base above the nozzle 42 and there is clearance above the nozzle for the accumulation of slack in the cable 58 and hose 59 when the nozzle is moved upwardly into a raised position.

The teeth of the rack 66 mesh with a pinion gear 69 driven by a reversible motor 70 through reduction gearing 72. This motor 70 is remotely controlled in a manner which will be explained in connection with the wiring diagram shown in Figures 15 and 16. For the present it is sufficient to understand that the operation of the motor 70 in one direction raises the nozzle 42, and operation of the motor 70 in the other direction lowers the nozzle 42 to control the diameter of the bore made by the drilling machine.

The reduction gearing 72 preferably includes a worm wheel of slow pitch so that the gearing is "irreversible," that is, the rotation of the motor 70 will raise or lower the rack but the weight of the rack and nozzle 42 cannot transmit rotation back through the reduction gearing 42 to the motor 70.

At the lower end of the exhaust passage 46 there is a screen 76 through which dust and small particles produced by the disintegration of the lithologic formation are sucked into the passage 46 by a suction blower 78 located in the thermo-base 22. The lower end of the exhaust passage 46 is preferably narrower toward the center of the housing, as shown in Figure 2; and the cross section of the passage 46 becomes progressively less in an upward direction and merges into a circular pipe 80 which forms the upper part of the passage 46 connecting with the suction blower 78. This reduction in cross section of the exhaust passage causes an increase in the velocity of flow of gas through the passage and carries the evacuated cuttings along at substantial velocity so as to reduce any possible tendency of the exhaust passage to clog when the flow of cuttings is heavy.

The bit 48 extends across substantially the full width of the housing 20 at a location where it is out of the gas

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stream so as to avoid being heated by impingement of the dissociated gas from the nozzle 42. The bit 48 is connected, near its opposite ends, with rods 82 leading upwardly through bores 83 (Figures 4-6) in the structure of the thermo-base, and the walls of these bores serve as bearings for the rods 82 as the rods reciprocate axially during operations of the bit 44 (Figure 2). The upper ends of these rods 82 are connected to a bit-operating electromagnetic motor 84 located above the suction blower 78 in the thermo-base.

In order to scour the face of the bore, and to carry the cuttings into position to be sucked through the screen 76 into the exhaust passage 46, there is a blast passage 90 opening through the bottom face of the thermo-base at one side of the nozzle 42 and directed at an angle across the portion of the bore face 40 on which the dissociated gas from the nozzle is acting. This blast passage 90 leads downwardly through the housing from a chamber 92 in which there is a blower 94 consisting of a motor 95 and fans 96 attached to opposite ends of the armature shaft of the motor 95. This blower 94 is merely representative of means for ejecting a blast of scouring gas from the blast passage 90 and across localized areas of the face of the bore to stir up the cuttings and cause them to move so that they will be drawn into the exhaust passage 46.

The blower 94 draws its gas from a chamber 98 through a screen 99. The upper end of the chamber 98 is connected by a passage 100 with the interior of the housing of the machine above the chamber 98 where there are quantities of gas which have already carried cuttings up to a mixer and separated from the cuttings at the mixer in a manner that will be explained in connection with Figure 9.

The upper end of the thermo-base 22 extends into the lower end of the middle section 24 of the drilling machine housing as shown in Figure 2. The portion of the thermo-base within the middle section of the housing 24 is freely rotatable about the longitudinal axis of the housing and the outside surface of the thermo-base, which is enclosed within the middle section 24, acts as a bearing in contact with the inside face of the middle section during the oscillating movement of the thermo-base as already explained.

In order to prevent longitudinal movement of the thermo-base 22, with respect to the middle section 24, there is a collar 104 secured within the lower end of the middle section 24. This collar 104 has a tapered bearing face confronting a complementary tapered face on the thermo-base to provide a thrust bearing for preventing upward movement of the thermo-base with respect to the section of the housing above it; and there are anti-friction bearings 106 between confronting faces of the collar 104 and a shoulder 108 of the thermo-base. These anti-friction bearings 106 carry the weight of the thermo-base 22, and in the ordinary operation of the drilling machine there is no upward thrust to produce friction between the tapered face of the collar 104 and the complementary tapered face of the thermo-base.

Power for oscillating the thermo-base 22 with respect to the middle section 24 of the housing is supplied by an electric motor 112. This motor includes a hollow shaft 114 secured to the upper end of the thermo-base 22. Armature coils 116, of the motor 112, are secured to the hollow shaft 114. This shaft 114 is the armature shaft of the motor. Field coils 118 of the motor 112 are secured to the side wall of the middle section 24 of the housing just above the upper end of the thermo-base 22. The motor 112 is reversible and in operation the current is supplied to the motor so as to oscillate the thermo-base 22 back and forth through an angle of oscillation of slightly less than 360°.

This oscillation permits the stream of dissociated gas to act successively on all parts of the face of the bore and it has the advantage, over a continuous rotation in

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one direction, that the conductors leading downwardly into the thermo-base can have sufficient slack to accommodate the oscillating movement, and slip rings are not necessary for conducting power into the thermo-base.

The automatic reversal of the motor 112 will be described in connection with Figure 7.

Another section of the cutting evacuation exhaust passage includes a pipe 125 leading from the discharge side of the suction blower 78 upwardly past the bit-operating mechanism 84 and past the magnetron 60 to the hollow shaft 114 of the motor 112. This pipe 125 extends through the hollow shaft 114 and into an upper stationary exhaust pipe 128 carried by the mid section 24 of the drilling machine housing. The upper end of the pipe 125 and the lower end of the stationary exhaust pipe 128 are in axial alignment and located on the axis of oscillation of the thermo-base 22 so that the pipe 125 oscillates as a unit with the thermo-base and within the lower end of the stationary pipe 128.

The hose 59 extends through the hollow shaft 114. This hose 59 is not on the axis of oscillation of the thermo-base but has sufficient resilience to twist enough to compensate for the angular movement of the thermo-base during its oscillation.

Figures 4, 5 and 6 show sectional views on the lines 4-4, 5-5 and 6-6, respectively, through the thermo-base 22 and the construction will be evident from the description already given in connection with Figure 2.

Figure 7 shows an automatic switch 129 for reversing the motor 112 each time the motor turns through an angle somewhat less than 360°. An abutment 130 carried by one of the armature coils 116 strikes against an offset switch lever 131, the offset of which is best shown in Figure 2.

Referring again to Figure 7, rotation of the armature of motor 112 in a clockwise direction causes the abutment 130 to move the lever 131 into the full-line position shown in Figure 7 and this puts the switch 129 in position to drive the motor 112 in a counter-clockwise direction. The switch 129 remains in the full-line position shown until the armature of motor 112 rotates far enough to bring the abutment 130 against the other side of the lever 131 to move that lever and the switch 129 into the dotted line positions, shown in Figure 7, and to reverse the motor again.

One of the field coils 118 is shown schematically as a wiring diagram at the left of Figure 7 to illustrate the connections whereby movement of the switch 129 between its two opposite positions reverses the direction of current flow in the motor to reverse the direction of rotation. In this figure, the other field coils are indicated by the legend "other field coils." The reversal of current provides, in effect, an electric brake for stopping each oscillation of the thermo-base at the end of its stroke. This switch 129 is merely representative of means for reversing the direction of rotation of the motor 112 to oscillate the thermo-base. No further explanation of the switch 129 and motor 112 is necessary for a complete understanding of this invention since two-position reversing switches and reversible electric motors are well understood in the art.

Figure 8 shows another suction blower 132 at the upper end of the stationary exhaust pipe 128 and this suction blower 132 pumps the gas and its entrained cuttings upwardly through another exhaust pipe 134 which forms a further section of the overall exhaust passage. Still another suction blower 136 is located higher in the drilling machine housing and this exhaust blower 136 pumps the gas and entrained cuttings into another section of exhaust pipe 138 which leads to a chamber 140. The direct run of the exhaust pipe 138 curves inwardly and downwardly into the upper end of the chamber 140.

A branch pipe 142 leads from the exhaust pipe 138 to a pump 145 located below the chamber 140 and having its housing communicating with the lower end of the

chamber 140. The pump 145 has a discharge pipe 150 leading upwardly to higher levels in the housing of the drilling machine.

The reason for having a plurality of suction blowers, including the blower 78 of Figure 2 and the blowers 132 and 136 of Figure 9, is to distribute the pumping load along the exhaust passage for more even flow, and in order to be able to use smaller motors on the individual suction blowers. Each of the suction blowers shown is an integral unit with its own motor supplied with electric power from the conduit conductor 63, as shown.

Above the chamber 140 there is a water pump 154 having its inlet side connected to a water supply pipe 156 and its discharge side connected to a water passage 158 opening into the top of the chamber 140. There are baffles 159 in the chamber 140 supported from the walls of the chamber and positioned at angularly and axially spaced locations in the path of the gas stream to partially obstruct the flow and cause local turbulence of the stream to facilitate mixing of the water vapor and the gas-entrained particles from the face of the bore.

There is one other opening in the top of the chamber 140 for a gas escape pipe 160. Along the length of the exhaust pipe 138, between the branch pipe 142 and the top of the chamber 140, there is a valve 162 for controlling the flow of gas and entrained cuttings through this exhaust pipe 138 to the chamber 140. Another valve 164 is located along the branch pipe 142 and ahead of the pump 145.

In the normal operation of the drilling machine, the branch pipe 142 is closed by the valve 164; and the valve 162 is open so that gas and entrained cuttings from the suction blower 136 are discharged into the upper end of the chamber 140. Within this chamber the cuttings are mixed with water which flows into the chamber from the water passage 158. This wets down the cuttings and makes a slurry which is pumped out of the bottom of the chamber 140 by the pump 145.

The gas in which the cuttings were entrained in their passage from the face of the bore to the chamber 140 escapes from the chamber 140 through the pipe 160. This pipe 160 discharges into the interior of the drilling machine housing. It is this gas which is drawn through the passage 100 (Figure 2) and which is discharged by the blower 94 through the blast pipe 90 for scouring the face of the cut and entraining new cuttings for passage upwardly through the exhaust passage and eventually to the chamber 140 (Figure 8).

When the drilling machine is lowered into a bore in which the working space adjacent to the face of the bore is flooded with water, the valve 162 is closed and the valve 164 in the branch pipe 142 is opened so that the water in the bore can be pumped out directly by the pump 145 without passing through the chamber 140. It will be understood that the suction blowers 78 (Figure 2) and 132 and 136 (Figure 8) can be operated independently of the other parts of the drilling machine, as will be shown clearly in connection with the wiring diagram of Figures 15 and 16, to pump water out of a flooded bore preparatory to the use of the dissociated gas nozzle for disintegrating the face of the bore when the bore is to be extended.

Above the chamber 140 and water pump 154, there is a gas storage cylinder 175 supported by a bracket 176 which is connected to the wall of the drilling machine housing. A valve 180 controls the flow of gas from the cylinder 175 and this valve 180 is operated by a solenoid 182; the valve 180 being normally closed and being opened by energizing of the solenoid 182. A pressure regulator 184 is connected with the outlet of the housing of the valve 180 and the pressure regulator 184 supplies gas to the tubing 59 which leads downwardly through the housing and eventually to the nozzle from which the stream of dissociated gas is projected against the face of the bore.

Figure 9 shows the upper end of the drilling machine

housing. There are other pumping stations 190 and 190' (Figure 9) for distributing the pumping effort along the length of the discharge pipe 150; and at its upper end the discharge pipe 150 opens through a top wall 192 of the housing and into the hollow interior of a fitting 194 by which the drilling machine is attached to the cable 28.

There are radially extending outlets 196 from the interior of the fitting 194, and the slurry containing the cuttings is discharged through these outlets 196 into a reservoir 198 formed by the extension of the side walls of the drilling machine housing above the top wall 192. The purpose of this reservoir is to provide a holder for the slurry which is to be raised to the head of the bore by a bailer. This bailer forms no part of the present invention and the slurry in the reservoir 198 can be pumped up to the head of the bore in the manner used for the mud from conventional drilling machines.

In the construction illustrated, the cable conductor 63, containing all of the conductors which extend between the electrical units of the drilling machine and control apparatus at the head of the bore, extends into the fitting 194 and passes upwardly through the center of the hoist cable 28. If no such special hoist cable is available, the cable conductor 63 can be led upwardly as a separate cable extending along the length of the bore.

Various expedients can be used for supplying water to the water supply pipe 156 (Figure 8), but for purposes of simplifying the disclosure, this water supply pipe 156 is connected with tubing 206 (Figure 9), leading to the head of the bore where water is supplied under the necessary pressure for carrying out the mixing step to form the slurry of cuttings in the chamber 140 (Figure 8).

Figures 10 and 18 show the apparatus for operating the bit which is connected to the lower ends of the rods 82. This apparatus, designated generally by the reference character 84, includes a center shaft 210 which slides up and down in bearings 212 and 213 at opposite ends of a casing 215. At an intermediate location along the shaft 210, and within the casing 215, there is a plunger 218 of ferrous metal secured to the shaft 210. The shaft is preferably made of non-ferrous metal since this increases the power of the bit-operating mechanism 84. At the lower end of the casing 215 there is a solenoid 223, and at the upper end of the casing there is similar solenoid 225.

When energy is supplied to the lower solenoid 223, the plunger 218 is pulled downwardly to cause the bit to contact with the spallings or cuttings in the bore to break them into smaller particles, as previously described. When energy is applied to the solenoid 225, the plunger 218 is raised to move the bit away from the face of the bore. There are springs 227 both above and below the plunger 218 for cushioning the stop at opposite ends of the stroke. Bosses 230 at the upper ends of the rods 82 provide positive stops for preventing excessive movement of the bit.

The rods 82 are connected with the shaft 210 by a cross-head 233; and this cross-head 233 slides in guides 235 attached to the bottom of the casing 215. The casing 215 is attached to the side wall of the thermobase by brackets 237 extending from the casing 215 to the inside wall of the lower section 22 of the housing, as best shown in Figure 18. These brackets are at angularly spaced locations around the housing and they support the casing 215 in spaced relation to the lower section 22 so as to leave clearance between the casing 215 and the housing for passage of the conductor cable 58, hose 59 and pipe 125, as well as any other power lines or pipe or tubing connections which may be used within the housing. The brackets 237 are rigidly fastened to the lower section 22 of the housing by brazing or any other conventional fastening means.

In order to provide an automatic reciprocating movement of the plunger 218, and the bit which the plunger operates, there is a switch 240 consisting of a drum 241

having an insulated sector around one-half of its circumference. Brushes on opposite sides of the drum 241 are each connected with a different one of the solenoids 223 and 225. This drum serves as a commutator which energizes the solenoids 223 and 225 alternately as the drum 241 rotates. The drum is on an axle 242 with a slip ring 243 to which power is supplied from a brush 244. This axle 242, which carries the drum 241 and the slip ring 243, is rotated by a motor 248. Power is supplied to the motor 248 and to the brush 244 from conductor cable 63 and through a switch at the head of the bore.

Figure 12 is a sectional view through one of the packers 36. The packer is made of elastic material, for example rubber, which normally occupies a retracted position such as shown in the dotted lines; the upper and lower edges of the packer material being clamped to the outside surface of the section 24 of the housing by clamping bands 266 which extend around the entire circumference of the drilling machine housing. There is a gas supply pipe 268 extending through the wall of the drilling machine casing for supplying gas to inflate the packer 36.

When inflated, the packer 36 is stretched to expand it into contact with the wall of the bore 30. Being of stretchable material, the packer will accommodate itself to any irregularities and roughness in the surface of the bore 30 and thus provide a seal around the entire circumference of the drilling machine between the outside surface of the drilling machine and the confronting face of the bore 30.

In order to provide gas under pressure for inflating the packer 36, tubing 270 extends upwardly through the drilling machine housing to a pressure regulator 280. The tubing 270 has four branches leading to the other packers 36, but not shown because the construction and control of the gas supplied to the other packers is the same as that illustrated in Figure 12.

The supply of gas to the packer 36, and the exhaust of gas from the packer, are controlled by a valve 285. This valve has an operating lever 286 which moves the plug of the valve angularly to put different ports of the valve in communication with each other. The operating lever 286 is normally held in the position shown in Figure 12 by a spring 288 tensioned between the lever 286 and a tab 289 connected to the inside of the housing.

When in the normal position shown in Figure 12, the valve port which connects with the pipe 268 is in direct communication, through the valve, with an exhaust port 290 so that the stretched material of the packer 36 can return to its normal position, forcing the gas out of the packer through the pipe 268, valve 285, and exhaust port 290 as the packer contracts.

A solenoid 292, supported from the upper end of the housing of the valve 285, has a plunger connected with the lever 286 by a pull rod 293. When the solenoid 292 is energized, it causes the operating lever 286 to move clockwise in Figure 12 and to shift the plug of the valve 285 into position to put the tubing 270 in communication with the pipe 268 through another passage in the plug of the valve 285 so that gas under pressure is supplied to the packer to inflate it. This valve 285 is shown diagrammatically and is merely representative of three-way valves which connect the interior of the packer 36 with a source of gas under pressure when in one position and put the interior of the packer into communication with an exhaust port when in another position.

Each of the packers 36 has its own control valve similar to the valve 285 and operated by a solenoid 292 with remote control, as illustrated in the subsequent wiring diagrams of Figures 15 and 16.

Figure 13 shows a modified construction of the nozzle for directing a stream of dissociated gas against the face 40 of the bore. A shell 300 is attached to the rack 66 and is adjustable toward and from the bore 40 in the same manner as the gas discharge nozzle shown in Figure 2. In place of the nozzle with the double wall and the curtain of gas directed from the clearance between the walls,

as in Figure 2, the construction shown in Figure 13 merely has two electrodes 301 and 302 carried by the wall of the shell 300 near its lower end. A gas stream 304 is directed downwardly through an arc established between the electrodes 301 and 302, and the gas is partially dissociated by passage through the arc. The gas stream 304 is projected from a nozzle orifice 306 which receives gas from tubing 59.

The gas stream 304 expands as it flows downwardly toward the face 40 of the bore, but the nozzle formed by the orifice 306 and shell 300 does not provide a comparable control of the gas flow as is provided by the nozzle 42 shown in the earlier figures. The arc discharged between the electrodes 301 and 302 in Figure 13 is not close enough to the face 40 to produce a direct arc heating. It does preheat the gas, but the reassociation of the gas molecules which are dissociated by passage through the arc is the source of localized heat which produces spalling of the lithologic formation of the face 40. This structure shown in Figure 13 is used in the same combination as illustrated in Figure 2 and the other figures and is being merely substituted for the nozzle 42 of Figure 2.

Figure 14 shows the lower anchors 34, each of which slides radially in a cylinder 308, formed in a partition wall 309 of the drilling machine housing. Each of the anchors 34 is operable independently of each of the other anchors. There is a spring 310 tensioned between each of the anchors 34 and a lug 311 at the inner end of the cylinder in which the anchor slides. Shoulders in the cylinders limit the inward movement of the anchors 34; and a stud 313 extending from the cylinder wall into a groove 314 limits the outward movement of each anchor with respect to its cylinder.

Gas flows to and from the cylinders 308 through passages 315 that open through the end walls of the cylinders. The flow of gas in each of the passages 315 is controlled by a three-way valve 316 (Figure 15) operated by a solenoid 317. The construction of the valve 316 and its operating mechanism is identical with that of the valve 285 shown in Figure 12. Gas is supplied to the valve 316 from tubing 270 connected with the pressure regulator 184 shown in Figure 8. There is a separate valve 316 and valve-operating solenoid 317 for each of the anchors. These valves 316 and their operating means are the same as the valve 285 shown in detail in Figure 12. Each anchor is held in retracted position by its spring when its solenoid 317 is not energized, and the anchor is thrust into its extended position when power is supplied to the solenoid 317 to move the valve 316 into position to supply gas to the anchor cylinder 308.

The operation of the preferred method and apparatus is as follows:

Power is supplied to the magnetron 60 (Figure 2) to produce a high frequency field between the inner and outer electrodes of the nozzle 42 at the bottom of the thermo-base 22. Gas is supplied through the tubing 59 to the nozzle 42 and is dissociated as it passes through the nozzle. The stream of dissociated gas, indicated by the lines 44 in Figure 2, strikes against the lithologic formation to be disintegrated and the reassociation of the gas upon striking the lithologic formation produces such highly localized heating that the surface of the lithologic formation spalls off, usually in the form of thin chips.

In order to prevent the spalled particles from being melted, and to prevent the heat from soaking into the lithologic formation so that the temperature gradients would become more gradual and the thermal stresses no longer disruptive, the thermo-base 22 is rotated to bring the gas stream into contact with a different area of the lithologic formation, and this is repeated so that the gas stream never impinges against any surface long enough to melt it, nor to permit heat to soak into the surface.

The actual cross section of the gas stream directed

against the lithologic formation, such as the face 40 of the bore shown in Figure 2, is a hollow rectangle, there being no gas directed against the face 40 immediately below the inner shell 51 of the nozzle 42. Upon reassociation of the gas of this hollow curtain of gas from the nozzle 42, disruptive thermal stresses are set up in the face 40 on all sides of the area which is immediately below the inner shell 51. This produces thermal wedges around the unheated portion and causes the unheated portion to spall off as chips, thus increasing the amount of material disrupted for a given quantity of dissociated gas.

During the disintegration of the materials of face 40 by the reassociation of the gas stream from the nozzle 42, a blast of air from the blast passage 90 scours the face 40 to keep the spallings and chips agitated; and the bit 43 reciprocates toward and from the face 40 to break up the chips into small particles for entrance through the openings in the screen 76 at the entrance of the exhaust passage 46 through which gas and entrained spallings or cuttings are sucked out of the chamber in the bore adjacent to the face 40.

The gas which is sucked out through the exhaust passage 48 is partly the scouring gas from the blast passage 90 and partly the reassociated gas which was originally discharged by the nozzle 42. Most of this gas is separated from the spallings or cuttings in the chamber 140 (Figure 8) where the cuttings are mixed with water to make a slurry, as previously explained. The gas escapes through the pipe 160 into the interior of the housing of the drilling machine. It is this free gas in the housing which supplies gas for the blower 94 (Figure 2). Thus the same scouring gas is used over and over again, being drawn through the passage 100 and chamber 98, and directed by the blower 94 through the blast passage 90 and again across the end face of the bore.

Since the gas which passes through the nozzle 42 is not changed chemically by its dissociation and reassociation, this gas can be used over and over again.

In order to recycle the gas through the nozzle 42, there is an outlet passage 320 on the downstream side of the blower 94 in the chamber 92. A valve assembly 322 has a cylindrical housing 323 with a port opening through the wall of the housing and communicating with the passage 320, and this cylindrical housing 323 has other ports communicating with the sections of the tube 59 above and below the housing 323; the housing being connected in series with the successive portions of the tube 59.

The operation of this valve 322 will best be understood by reference to Figures 15 and 19. A valve element 325 is normally held at one end of the housing 323 by a tension spring 327. This valve element 325 slides as a piston in the housing 323 of the valve assembly 322. A plunger 328 is connected with the other end of the valve element 325 and is moved against the pull of the spring 327 by a solenoid 330 whenever the solenoid is energized. There is a passage 331 through the valve element 325 and when the valve element 325 is in the position shown in Figures 15 and 19, a port 332 in the valve housing 323 above the valve element communicates with a port 332' below the valve element 325. These ports 332 and 332' are the ones that communicate with the sections of the tubing 59 above and below the valve assembly 322.

When the solenoid 330 is energized at a predetermined voltage, it moves the valve element 325 toward the right in Figure 15, and the passage 331 in the valve element 325 is moved beyond the port 332 and this same movement causes the passage 331 to uncover the port connected with the passage 320. The passage 331 through the valve element, immediately above the port 332', is wide enough to establish communication between the passage 320 and the port 332' (shown in dotted lines in Figure 19) when the valve element 325 is shifted into this new position where the pull of the solenoid 330

balances the tension of the spring 327. Thus gas in the chamber 92 (Figure 2) flows through the passage 320 and through the valve 322, and downwardly through the tubing 59 to the nozzle 42. The blower 94 provides the necessary increase in gas pressure to cause the recycled gas from the upper part of the housing to pass through the nozzle 42 with sufficient velocity to impinge directly against the face 40 of the bore.

The valve 322 can be operated with a higher voltage on the solenoid 330 so that the valve element 325 moves to the right far enough to cover the port 332 and shut off all gas. By manual or other intermittent operation of this valve 322 to shut off the gas, the stream of gas against the face of the bore can be supplied in pulses and with resulting intermittent stabs of heat. This valve assembly 322 is operated by manually shifting the switch 355 (Fig. 16) but it is obvious that various automatic means can be embodied to perform the operation.

Although the supply of gas from the storage cylinder 175 (Figure 8) through the tubing 59 is shut off by the movement of the valve 322 (Figure 2) into position to supply gas from the chamber 92 through the passage 320 to the nozzle 42, the supply of gas from the storage cylinder 175 (Figure 8) is also controlled by the solenoid-operated valve 180. As in the case of valve assembly 322, this solenoid-operated valve 180 is shown with a manually operated control switch 391 (Fig. 16) but can have automatic control.

As the bore 30 is advanced by disintegration of the material of the end face 40 of the bore, the drilling machine is advanced by lowering the cable to locate the machine deeper into the bore, the packers 36 being deflated as necessary in order to permit the drilling machine to move downwardly in the bore.

Different kinds of auxiliary equipment for determining the spacing of the end of the drilling machine from the bore face 40, the temperatures and pressures within the bore, and other information which may be useful to the operator are not shown in the drawing since an explanation and illustration of them is not necessary for a complete understanding of this invention. It should be understood, however, that the drilling machine shown can be used with any conventional auxiliary equipment as desired for indicating position, orientation and various physical conditions in connection with the operation of the machine.

The position of the nozzle 42 is preferably determined by connecting the motor 70, which adjusts the height of the nozzle 42, with a selsyn motor 340 (Figure 16) at the head of the bore. This selsyn motor 340 is connected through rack and pinion mechanism 344 to an indicator 346 which moves as a unit with the rack along a scale 348 for determining the height of the nozzle above the bottom of the thermo-base.

The position of the indicator 346 along the scale 348 is a measure of the extent to which the nozzle of the drilling machine is moved downwardly from its highest position with respect to the thermo-base. Raising and lowering of the indicator 346 manually by the operator turns the pinion mechanism 344 and rotates the master motor 340. This motor is connected by a three-conductor circuit with the slave motor 70 in the thermo-base of the machine. The connections of the armature circuits and windings of the motors 340 and 70 are such that the armature in the slave motor 70 moves to any angular position to which the armature in the master motor 340 is moved. Such remote control devices are used for artillery and many other purposes and are well understood in the art. No further illustration of the circuits is necessary for a complete understanding of this invention.

The various switches for remotely controlling the operation of different parts of the drilling machine are indicated in Figure 16 by legends and are shown connected with the apparatus they control by conductors. The se-

quence of operation of the different elements of the machine is performed by manual operation of the different switches in the construction illustrated. An operator familiar with the intended sequence of operation knows the order in which to move the different switches. For example, the valve assembly 322, which controls the recycling of the gas, is controlled by a manually-operated switch 355 controlling the supply of power to the valve-actuating solenoid 330. All of the blowers and pumps 78, 95, 132, 145, 190 and 190' are supplied with power by a manually-operated common control switch 358. The power supply to the magnetron 60 is controlled by a switch 360; and a switch 362 supplies power for the motor 112 that oscillates the thermo-base.

There are individual switches 371, 372, 373, 374 and 375 for the five different packers 34. There are also individual switches for the different anchors, including switches 381, 382, 383 and 384 for the upper anchors 34 and corresponding switches 385, 386, 387 and 388 for the lower anchors 34.

The only pump which is independently controllable is the water pump 154. The supply of power to the motor of that pump is controlled by a switch 390. The valves 162 and 164 associated with the slurry chamber are controlled by switches 391 and 392, respectively.

A switch 394 controls the opening and closing of the main valve 182 for the gas supply from the storage cylinder 175. The bit-operating motor 84 is supplied with power through a shut-off switch 396.

All of the conductors for these switches come together within the cable conductor 63 which leads downwardly through the bore to the drilling machine. The parts in Figure 15 are indicated by the same reference characters as in the other figures and the wiring of the machine will be apparent from Figures 15 and 16, bearing in mind that all of the conductors at the top of Figure 15 are continued upwardly from the bottom of Figure 16 and in the same order from left to right. All of the control means shown in Figure 16 are at ground level near the entrance to the bore and preferably at a central control station.

The various switches in the central control station can be equipped with operating devices controlled from a master cam feed or from a record designed to produce the proper sequence of operation. However, they can be manually operated and in the apparatus shown in Figure 16, the switches are manually operated. Anyone knowing the way in which the drilling machine operates, and knowing the positions of the various parts at each instant, can control the operation by moving the various switches manually to obtain the operation and the necessary sequences within the bore in which the machine is operating.

In the preferred construction of the invention, remote control indicators are provided for giving the operator information on the positions of parts and the orientation of the machine in the ground. In order to simplify the invention, these remote control indicators are not included in the drawings since they are not necessary for a complete understanding of the invention, and conventional indicators can be used for giving any information which is desired by the operator at the central control station.

The preferred embodiment of the machine has been illustrated, but changes and modifications can be made and some features can be used in different combinations without departing from the invention as defined in the claims.

What is claimed is:

1. The method of advancing a bore through a lithologic formation, which method comprises sealing off a portion of the bore adjacent to the end face thereof to isolate said portion of the bore, evacuating from said portion any water as it accumulates therein, and by said evacua-

tion providing a chamber across the end face of the bore adapted to receive a gas, introducing a dissociated gas into a localized region of said chamber and positioning the stream of gas so that it impinges against the end face of the bore, thereby causing reassociation of said gas and the generation of high intensity heat on said face of the bore, the dissociated gas when introduced into said localized region being confined to a predetermined stream so that it impinges against only a predetermined and limited area of the end face of the bore, maintaining the application of the stream to the limited area of the formation for a time sufficient only to raise the temperature of the formation to a temperature sufficient to spall the formation but below the fusion temperature thereof to cause disruption of material in a substantially solid state from said limited area, subsequently and similarly impinging dissociated gas in said chamber on other limited surface areas of the end face of the bore with a consequent generation of heat and disruption of material at said other limited surface areas and collecting and withdrawing the reassociated gas from the different parts of the sealed-off chamber during the times of impingement and with particles of the disrupted material entrained therein.

2. In the making of bores in a lithologic formation in the earth by progressively disintegrating material from an end face of the bore by the creating of disruptive stresses produced by the application of heat, the improvement which comprises sealing off the end portion of the bore from the outside atmosphere, evacuating from said end portion of the bore any water as it accumulates therein, and by said evacuation providing a chamber across the end face of the bore adapted to receive a gas, projecting short pulses of dissociated gas into a localized region of said chamber and against a predetermined and limited area of the end face of the bore, thereby causing disruption of material in said chamber from the said end face in a substantially solid condition by the heat produced by reassociation of the dissociated gas striking said end face, limiting the time of impingement against said limited area to prevent substantially any melting of the disrupted material, and evacuating the disrupted material in its substantially solid condition from the vicinity of the end face of the bore.

3. In the making of bores in the earth by disintegrating material from a lithologic formation at an end face of a bore with disruptive stresses thermally set up by heating of different portions of the formation, the improvement which comprises evacuating from the end portion of the bore any water as it accumulates therein, and by said evacuation providing a chamber across the end face of the bore adapted to receive a gas, supplying dissociated gas to the chamber, the dissociated gas being directed toward the end face of the bore and said dissociated gas being confined to a spread stream with substantially no gas flow in the mid portion of the cross section of the stream so that the gas impinges against only predetermined and limited areas of the end face of the bore but impinges substantially simultaneously against areas that are spaced from one another by predetermined distances while the surface between said areas confronts the mid portion of the cross section of the stream and is free of any direct impingement by the dissociated gas, and generating high intensity heat on the spaced areas of the end face by reassociation of the gas to cause severing from the formation, in a substantially solid condition, the material at and between the spaced areas by the thermal expansive forces produced at and immediately below the areas exposed to the reassociation of the gas during the heating step, limiting the time of impingement against said limited area to prevent substantially any melting of the disrupted material, and repeating the impingements of dissociated gas on other spaced areas of the end face of the bore with the subsequent generation

of heat and severing of material at and between said other spaced areas.

4. The method of advancing a bore through a lithologic formation, which method comprises evacuating from the end portion of the bore any water as it accumulates therein, and by said evacuation providing a chamber across the end face of the bore adapted to receive a gas, introducing a dissociated gas into a localized region of said chamber and impinging the dissociated gas against the end face of the bore, thereby causing reassociation of said gas and the generation of high intensity heat on said face of the bore, the dissociated gas when introduced into said localized region being confined to a predetermined stream so that it impinges against only a predetermined and limited area of the end face of the bore to cause disruption of material in a substantially solid state from said limited area, limiting the time of impingement against said limited area to prevent substantially any melting of the disrupted material, collecting the reassociated gas at a predetermined and limited region of the chamber spaced from the area of the end face against which the dissociated gas impinges, withdrawing the reassociated gas from said chamber with particles of the disrupted material entrained therein and then repeating the impingement of dissociated gas in said chamber on different limited surface areas of the end face of the bore with a consequent generation of heat and disruption of material at said different limited surface areas, and collecting and withdrawing the reassociated gas from the different areas of the end face and with particles of the disrupted material from said different areas entrained therein, the method being characterized by directing the dissociated gas against the end face of the bore in a stream which diverges as it approaches the end face and controlling the area of impingement of the gas stream on the end face of the bore by moving the gas stream in the direction of its flow so that the extent of divergence determines the area of impingement.

5. The method of advancing a bore in the earth, as described in claim 1, characterized by varying the position of the dissociated gas stream to change the area of impingement of the stream against the end face.

6. The method of advancing a bore in earth, as described in claim 1, characterized by preheating the gas prior to dissociation to facilitate and increase the degree of dissociation.

7. The method of making bores in the earth, as described in claim 1, characterized by directing an additional stream of gas into the space adjacent to the end face to increase the amount of gas available for entraining the substantially solid fragments that are to be carried from said space.

8. The method of making bores in the earth, as described in claim 1, characterized by mechanically breaking some of the fragments by percussion against a restricted area of the end face of the bore, while the dissociated gas is impinging against a different area, so that the disrupted fragments are in smaller particles for evacuating by entrainment in the gas flowing from the space adjacent to the end face.

9. The method of making bores in the earth, as described in claim 1, characterized by transporting the substantially solid fragments, entrained in the gas, to a region intermediate the ends of the bore but remote from the end face of the bore, mixing the fragments with a liquid carrier at the remote region, and removing the fragments from the immediate region of the bore in the liquid carrier.

10. The method of making bores in the earth, as described in claim 3, where the spread stream has a continuous periphery whereby the end face of the bore is heated simultaneously along other spaced areas interposed between the previously described spaced areas so as to completely surround the surface which is free of impingement of the dissociated gas.

11. An earth-boring machine for making bores in a lithologic formation, said machine having a housing with a leading end that confronts the end face of a bore, means carried by the housing for sealing off a portion of the bore, adjacent to the end face thereof, to isolate said portion of the bore, earth penetrating means carried by the leading end of the housing and including a gas projector which confronts the end face of the bore, means carried by the leading end of the housing in position to dissociate gas of a stream of polyatomic gas directed against the end face of the bore, by the gas projector to generate high intensity heat at the surface of the face by reassociation of the gas, means for maintaining the application of the stream to the end face for a time sufficient only to raise the temperature of the formation to a temperature sufficient to spall the formation but below the fusion temperature thereof, and evacuating means, carried by the housing, for continuously collecting and withdrawing the reassociated gas from the sealed-off chamber and with particles of disrupted material entrained therein.

12. An earth boring machine for making bores in a lithologic formation, said machine having a housing with a leading end that confronts the end face of a bore, means carried by the housing for sealing off a portion of the bore adjacent to the end face thereof to isolate said portion of the bore, earth penetrating means carried by the leading end of the housing and including a gas projector which confronts a portion, and only a portion, of the end face of the bore, means carried by the leading end of the housing in position to dissociate gas of a stream of polyatomic gas directed against said portion of the end face, by the gas projector, bearing means in the housing from which the gas projector, is supported and on which it is movable into different positions to confront different portions of the end face for projecting the gas stream against said different portions successively, motor means carried by the housing and operably connected with the gas projector for moving the gas projector on said bearing means, means carried by the housing for controlling the duration of the impingement of the gas stream to the face of the bore, and evacuating means, carried by the housing for removing any water and for removing substantially solid fragments from the vicinity of the end face of the bore.

13. The earth boring machine described in claim 12, in which the means to dissociate the gas includes electric means carried by the machine in a region adjacent to the gas projecting means.

14. The earth boring machine described in claim 12, and in which the means to dissociate gas comprises electrodes located adjacent to the gas projecting means in position to provide an arc field through which the stream of gas passes as it travels toward the end face.

15. The earth boring machine described in claim 12 and in which the means to dissociate the gas comprises an electric apparatus carried by the machine providing an ultra high frequency electromagnetic field through which gas passes on its way to the end face of the bore.

16. The earth boring machine described in claim 12, and in which the gas projector includes a deflector in the outlet having a surface at an angle to the direction of the gas stream flow and in position to separate parts of the gas stream from one another so that said parts of the gas stream impinge against spaced portions of the end face for heating said portions while another portion of the end face between the heated portions, is substantially free of impingement of dissociated gas.

17. The earth boring machine described in claim 12, and in which the gas projector is shaped to direct a diverging stream of dissociated gas against the end face of the bore, and means for adjusting the gas projector toward and from the face of the bore to change the extent of divergence and thereby the resulting areas of

the different portions against which the gas stream successively impinges.

18. The earth boring machine described in claim 12, and in which the gas projector has at least a portion of its outlet facing in a direction to direct the gas stream outwardly beyond the forwardly projected cross section of the machine so that the bore produced by the dissociated gas is larger than the cross section of the machine, and means for changing the path of at least a portion of the gas stream to control the cross section of the bore produced by the dissociated gas.

19. The earth boring machine described in claim 12, and in which there are means for heating the gas which forms the stream of dissociated gas that is directed against the end face of the bore.

20. The earth boring machine described in claim 12, and in which there is a compressed gas chamber in the drilling machine from which gas is supplied to the gas projector from which the stream of dissociated gas is directed against the end face of the bore.

21. The earth boring machine described in claim 12, and in which there are packing means located around the sides of the machine in a clearance between the machine and the sides of the bore for preventing the entrance of water or other liquid from the bore into the space ahead of the packing means and between the leading end of the machine and the end face of the bore against which the stream of dissociated gas is directed.

22. The earth boring machine described in claim 12, and in which there is a passage in the drilling machine for the recirculation of gas which has been projected against the face of the bore and then drawn into the evacuating means, said passage having an entrance communicating with a space in the machine through which gas passes after removal from the vicinity of the end face of the bore by the evacuating means, said re-circulation passage having a discharge end at the leading end of the machine in communication with the space in front of the machine and adjacent to the face of the bore, and a blower in the re-circulation passage for pumping gas through the re-circulation passage.

23. The earth boring machine described in claim 12, and in which the evacuating means are connected with the gas projector for movement as a unit therewith, the evacuating means including an exhaust conduit having an entrance confronting a portion of the end face of the bore different from that which the gas projector confronts so that the substantially solid fragments are removed by the evacuating means at a different location confronting the end face from that at which the dissociated gas is directed against the end face.

24. The earth boring machine described in claim 12, and in which there is a mechanical percussion tool located in the space between the leading end of the drilling machine and the end face of the bore, and operating mechanism for moving the percussion tool to break up at least some of the substantially solid fragments into smaller pieces for removal by the evacuating means, and common connecting structure by which the gas projector, percussion tool, tool-operating mechanism, and evacuating means are all supported from said bearing means and movable together as an assembly by said motor means into different positions to confront different portions of the end face of the bore.

25. The earth boring machine described in claim 12, and in which the evacuating means include a conduit having an entrance opening through the leading end of the machine in a position confronting the end face of the bore, and the evacuating means include a blower in the conduit and a motor that operates the blower in a direction to exert a suction for drawing gas and entrained fragments of the lithologic formation into the conduit.

26. An earth boring machine for making bores in a lithologic formation, said machine including a leading end portion that confronts the end face of a bore, earth

penetrating means carried by the leading end portion of the machine and including a gas projector which confronts a portion, and only a portion, of the end face of the bore, means carried by the leading end portion of the machine in position to dissociate gas of a stream directed against the end face by the gas projector, bearing means in the machine from which the end portion is supported and on which the end portion has angular movement about a longitudinal axis of the machine for shifting the end portion into different positions so that the gas projector confronts different portions of the end face of the bore for projecting the gas stream against said different portions successively, evacuating means carried by the leading end portion of the machine for removing water from the vicinity of the end face of the bore and for removing substantially solid fragments of lithologic formation from the vicinity of the end face of the bore, the evacuating means including a passage through said leading end portion and into which the fragments are drawn, anchors carried by a rearward portion of the machine at locations back from the leading end portion, means for projecting the anchors against the sides of the bore for holding the rearward portion of the machine stationary in the bore, and motor means carried by the rearward portion of the machine and operatively connected to the leading end of the machine for moving said leading portion on said bearing means about the longitudinal axis of the machine.

27. An earth boring machine for making bores in a lithologic formation, said machine including a leading end portion that confronts the end face of a bore, earth-penetrating means carried by the leading end portion of the machine and including a gas projector which confronts a portion, and only a portion, of the end face of the bore, means carried by the leading end portion of the machine in position to dissociate gas of a stream directed against the end face by the gas projector, bearing means in the machine from which the end portion is supported and on which the end portion has angular movement about a longitudinal axis of the machine for shifting the end portion into different positions so that the gas projector confronts different portions of the end face of the bore for projecting the gas stream against said different portions successively, and evacuating means carried by the leading end portion of the machine for removing water from the vicinity of the end face of the bore and for removing substantially solid fragments of lithologic formation from said chamber in the vicinity of the end face of the bore, the evacuating means including a conduit opening through the leading end portion of the machine at a location confronting the end face of the bore, a blower in the conduit for pumping fluid and entrained solid fragments rearwardly in the machine and away from the end face of the bore, said conduit extending from the leading end portion of the machine into the part of the machine rearward of the leading end portion and having two sections, one of which moves as a unit with the leading end portion of the machine, and the other of which is integral with the part of the machine which is rearward of the leading end portion, and a connection between the sections of the conduit having a circular cross section and an axis substantially co-incident with the axis about which the leading end portion turns when moving on said bearing means.

28. An earth boring machine having a leading end portion that confronts the end face of a bore in a lithologic formation, gas projecting means on the leading end portion of the machine in position to direct a stream of gas against said end face, means to dissociate gas of said stream as it is projected toward the end face, means to cause intermittent flow of the stream of dissociated gas and thereby intermittently apply disintegrating thermal stresses to the end face of the lithologic formation of the end face of the bore by reassociation of the gas upon

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contact with said face, packing means around the sides of the drilling machine movable into contact with the sides of the bore at a location spaced from the vicinity of the end face of the bore for preventing entrance of water from the portion of the bore behind the packing means into the space between the leading end face of the machine and the confronting end face of the bore, and means including a passage, through the leading end portion of the machine, to evacuate substantially solid fragments of material disintegrated from the end face by said intermittent heating.

29. An earth boring machine for making bores in lithologic formation, said machine having a rearward portion and a leading end portion that confronts the end face of a bore and that is movable angularly about a longitudinal axis of the machine, earth penetrating means carried by the leading end portion of the machine and including a gas projector which confronts a portion, and only a portion, of the end face of the bore, means carried by the leading end portion of the machine, in position to dissociate gas of a stream directed against the confronting portions of the end face by the gas projector, bearing means on the rearward and leading end portions of the machine on which the leading end portion has its angular movement about the longitudinal axis of the machine to move the gas projector into different positions to confront different portions of the end face for projecting the gas stream against said different portions

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successively, packing means carried by the rearward portion of the machine around the outside of the machine, the packing means being movable into extended positions in which they contact with the sides of the bore to seal any clearance between the drilling machine and the sides of the bore around the entire circumference of the drilling machine to prevent entrance of liquid, from above the packing means, through said clearance into the space in the vicinity of the end face of the bore and in which the dissociated gas impinges against the end face, and evacuating means, also carried by the leading end portion of the machine, for removing substantially solid fragments from the vicinity of the end face of the bore.

References Cited in the file of this patent

UNITED STATES PATENTS

1,025,029	Sutton	Apr. 30, 1912
1,993,641	Aarts et al.	Mar. 5, 1935
1,993,642	Aarts et al.	Mar. 5, 1935
2,286,191	Aitchison et al.	June 16, 1942
2,308,860	Clark	Jan. 19, 1943
2,548,463	Blood	Apr. 10, 1951
2,587,331	Jordan	Feb. 26, 1952

FOREIGN PATENTS

147,729	Switzerland	Sept. 1, 1931
---------	-------------	---------------