This invention relates to the treatment of underground formations and, more particularly, this invention relates to a heater suitable for use in boreholes.

Various techniques have been proposed for the recovery of petroleum from underground formations. In this technique, as practiced in secondary recovery operations, the petroleum producing formation in the vicinity of a borehole or injection well is heated to a high temperature, for example 1000°F., and oxidizing gas, such as air, is supplied to the underground formation. The combustion gases produced around the borehole migrate through the formation to an output well or wells leading from the formation from which a petroleum product is removed.

In accordance with this invention an improved electrical heater is provided for initiating combustion of the hydrocarbon material in the subsurface formation, which is a simple, rugged construction capable of withstand- ing greater thermal shock due to rapid temperature changes than can prior art electrical borehole heaters, and can operate at higher temperatures for longer periods of time. Heat from the heater is introduced into the borehole at a relatively rapid rate until there exists a high temperature zone around the borehole sufficient in extent to sustain the in situ combustion process.

The heater, in addition to being useful in secondary recovery operations, may also be used for the carbonization of the area around the well as a means of making it preferentially weitable to oil and thereby to improve permeability. Furthermore, the heater may be used for removal of moisture in subsurface formations in the vicinity of the well bore and for any other application where a concentrated high temperature is desired. The heater of the present invention comprises an electrically resistive wire wound in the form of a helix threaded through annular insulators carried by an elongated support structure.

For a better understanding of the invention, reference may be had to the accompanying drawing in which:

FIG. 1 is a vertical sectional view through a portion of a borehole traversing subsurface formations showing therein the general arrangement of the apparatus used in accordance with this invention.

FIGS. 2, 2a, 2b, 2c and 2d illustrate in more detail the apparatus shown in FIG. 1.

FIG. 3 illustrates the electrical circuitry used in the apparatus of this invention.

FIG. 4 illustrates the heater element supporting frame of the apparatus of the invention.

FIG. 5 is a cross-sectional view of the apparatus at 5 of FIG. 2b.

FIG. 6 is a cross-sectional view of the apparatus at 6-6 of FIG. 2b.

FIG. 7 is a cross-sectional view of the apparatus taken at 7-7 of FIG. 2b, and

FIG. 8 is a cross sectional view of the apparatus taken at 8-8 of FIG. 2c.

Referring to the drawing wherein like reference numerals refer to similar elements illustrated in the various figures, there is shown in FIG. 1 a borehole 10 traversing a producing formation 12. The upper portion of the borehole 10 is lined with a casing 14 having a closed casing or braden head 16 at the upper end thereof.

The well heating system or electrical borehole heater of the present invention which is suitable for use to heat a subsurface formation, such as formation 12, in the vicinity of a borehole comprises a heater housing 18 which includes a thin sheath 20 having a 4½" outside diameter and a suitable length depending upon reservoir thickness, for example, 15 feet, a bottom plug 22 attached to the sheath 20 so as to be removable and a heater head 24 attached to the upper end of the sheath 20, a power cable 26 which is connected to a pair of heater elements 140 and 142 disposed within the sheath 20, temperature signal cable 28 which contains seven copper conductors for transmitting electrical signals indicative of temperature throughout the sheath, and a thermistor 76 to the earth's surface through suitable openings in the casing head 16, and a protective cable tubing 32 attached at its lower end to the heater head 24 and at its upper end to a cable cross-over 34 having an inside structure for receiving the cables 26 and 28 so as to introduce these cables into the protective tubing 32. The cable cross-over 34, protective cable tubing 32, and the heater housing 18 are supported in the borehole by well tubing 36 having a pup-joint 38 at the lower end thereof, which tubing is suspended from the casing head 16. The power cable 26 and the signal cable 28 are supported in the well by a plurality of ties 21 made of suitable banding material attached to the well tubing 36 at longitudinally spaced points. Connected to the upper end of the well tubing 36, preferably through a valve 39, is a gauge 40 for indicating the pressure in the borehole 10. A pipe 42 having a valve 44 is connected to the upper portion of the casing 14 to introduce an oxidizing gas, for example, air, into the borehole. The heater housing 18 has a heating section 27 located in the lower portion thereof and a heat baffle section 23 located in the upper portion thereof.

The four thermocouples 29, 30, 31 and 33 are disposed in the heater housing 18 at longitudinally spaced apart points.

As shown in more detail in FIGS. 2, 2a, 2b, 2c, and 2d, the apparatus of the present invention includes a hanger head 46 having a shoulder 47 at the upper portion thereof as shown herein supported on the edge of a first pipe 49 disposed between the cable cross-over 34 and the pup-joint 38 of the well tubing 36. A top plug 43 having a circumferential groove therein containing an O-ring 45 is disposed within the lower end of the pup-joint 38 to provide a seal between the interior of the pup-joint 38 and the interior of the first pipe 49. The pup-joint 38 and the first pipe 49 are coupled together by a first coupler 55. A chain hanger 48 having a loop 51 at the lower end is inserted through an opening or passageway in the hanger head 46 and is supported by a wing nut 50 threaded thereon. The power cable 26, which includes two relatively high potential conductors 17 and 19, is introduced into the cable cross-over 34 through a passage 53 in a cable cross-over head 54. A packing gland 55 and a packing screw gland 59 surround the cable 26 within the cable cross-over head 54 so as to provide a fluid-tight joint. A set screw 60 is inserted into the cable cross-over head 54 to restrain the power cable 26 in the passage 53. The signal cable 28 is similarly introduced into the cable cross-over 34 through a passage 62, a packing gland 64 and a packing screw gland 66. The cross-over head 54 also has a gas entry port and valve 25 communicating with the passage in which the chain hanger 48 is disposed to introduce an inert gas into the cable cross-over 34 and the protective cable tubing 32. The valve 25 may be protected by a suitable pipe.
plug 59. An O-ring 68 is disposed in a circumferential groove in the cross-over head 54 so as to form a fluid-tight seal between the cross-over head 54 and a cylinder 69 which is the cross-over 34. Attached to the loop 51 of the chain hanger 48 is a chain 72 for supporting the cables 26 and 28 within the cable protective tubing 32. Suitable ties 74, which are made preferably of stainless steel annealed wire, are used to lash the cables 26 and 28 to the chain 72. One of the seven copper conductors of the signal cable 26 is mounted within the cable cross-over 34 so as to provide an indication of the temperature therein. A cable cross-over adapter 77 having a circumferential groove containing an O-ring 79 couples the cable cross-over 34 to the protective cable tubing 32. Thermocouple wires 73 of the four thermocouples 29, 30, 31 and 33, which are preferably made of material known by the trade name Alumel and Chromel, are connected to the remaining five conductors of the signal cable 28 in the cable cross-over 34 at a cold junction terminal 75 in the vicinity of the thermistor 76. The power cable 25, as shown in FIG. 2b, of the four double wires 73 are supported within the heater head 24 by means of cable clamps 78 and a cable bracket 80 attached to a vertical support member 81 mounted on a supporting block 84. Disposed within the heater head 24 is the uppermost or first thermocouple 29, as shown in FIG. 2b. An O-ring 83 is contained in a groove disposed around the lower portion of the heater head 24 to provide a seal between the heater head 24 and the supporting block 84. The supporting block 84 has a pair of O-rings 92 to form a seal between the supporting block 84 and the sheath 20 of the heater housing 18. The supporting block 84 also has a gas entry port and valve 86 communicating with a passage 88 which is used to introduce an inert gas into the heater housing 18. The valve 86 may be protected by a suitable pipe plug 90. The supporting block 84 further includes a shoulder 85 supported by the upper edge of the sheath 28. The supporting block 84 is firmly held in position within the sheath 20 by a plurality of set screws 94, as shown more clearly in FIG. 7 of the drawing.

FIG. 2b of the drawing shows the two power leads 17 and 19 passing through passageways 100 and 102 in the supporting block 84, a seal being provided between each of the power leads 17 and 19 and the supporting block 84 by a packing 104 and a packing gland 106. The wires 73 of the three thermocouples 30, 31 and 33 disposed in the heating section 27 of the heater are fed through a passageway 108 in the supporting block 84 and a packing gland 104 and a packing gland 112 provide a seal between the thermocouple wires 73 and the supporting block 84.

A heater element support frame 114 is suspended from the supporting block 84 by means of a plurality of frame hangers 116. The frame hangers 116 are preferably welded to the supporting block 84 and the support frame 114 is secured to the frame hangers 116 by means of a nut and bolt arrangement 115, as shown in FIG. 6 of the drawing. The supporting frame 114 comprises an elongated plate 120 and two elongated L-shaped members 122 and 124 welded to opposite faces of the plate 120 to provide a frame having a cruciform transverse cross-section, as shown more clearly in FIG. 4 of the drawing. The frame 114 extends from the supporting block 84 continuously through the heat baffle section 23 and the heating section 27 of the heater housing 18 to a point spaced a given distance from the top of the bottom plug 22 to allow for differential expansion associated with temperature changes in the heater housing 18. The outer edges of the cruciform frame 114 are spaced from the sheath 20 of the heater housing 18 also to allow for differential expansion due to temperature changes. The outer sheath 20 of the heater housing 18 and the portion of the supporting frame 114 within the heating section 27 of the heater housing 18 are preferably made of Inconel which includes Ni(77.0°), Cu(0.2°), Fe(7.0°), Mn(0.2°), Si(0.2°), C(0.08°), S(0.007°), and Cr(15.0°). The portion of the supporting frame 114 within the baffle section 23 is preferably made of stainless steel. A plurality of lead-in brackets 126 each having a U-shaped edge opening to define a saddle for receiving an annular insulator 127, preferably made of ceramic material such as that known by the trade name Alsimag #222, for restraining one of the two power conductors or leads 17, 19 mounted on the supporting frame 114, as shown in FIGS. 2b, 2c, 4 and 5. Also mounted on the supporting frame 114 are an upper heat baffle 128 and a lower heat baffle 130 disposed in the heat baffle section 23 to protect the heater head 24 and the cables 26 and 28 at the upper portion of the heater from the high temperatures produced in the heating section 27. The heat baffles 128 and 130 are preferably made of insulator-fiberfrax ceramic fiber paper. The thermocouple wires 73 of the supporting frame 114 but insulated therefrom by means of a plurality of straps 131. The thermocouple wires 73 are insulated throughout their entire length to a point spaced a short distance from their hot junction terminals, a first hot junction terminal 30 being located at the upper end, a second hot junction terminal 31 at the mid-point and a third hot junction terminal 32 at the lower end of the heating section 27.

In the heating section 27 of the heaters the power conductors 17 and 19 are terminated at power lead terminals 132 and 134, respectively, to which they may be welded. A plurality of saddles 115 are formed in each of the four outer edges of the supporting frame 114 in the heating section 27 by removing a cup-shaped or U-shaped portion therefrom, the spacing between the saddles 115 being preferably greater at the mid-portions (not shown) than at the ends of the heating section 27. Annular insulators 127 are also inserted in each of the saddles 115 and held therein by retaining fingers or arcuate arms 138 made by deforming a portion of the frame 114 embracing the annular insulators 127 at their outer periphery. This structure is consistent for all saddles 115 although only specifically illustrated in FIG. 4 and the upper left hand few saddles of FIG. 2c, for sake of convenience.

The heating section 27 contains two heater elements 140 and 142. Each of these heater elements is wound in the form of a helix having a minor constant or uniform radius forming a first coil which coil is in turn wound in the form of a helix of major constant or uniform radius forming a second coil insulated between the saddles 115 of the frame 114 to form a second coil extending from one of the two power lead terminals 132, 134 located at the upper end of the heating section 27 to the lower end of the frame 114 and returning to the upper end of the heating section 27 to the other of the two power lead terminals 132 and 134 to provide electrical connection to the power leads 17 and 19. The heater elements in the double helical form are threaded through the annular insulators 127 so as to be supported by and electrically insulated from the supporting frame 114, as shown in FIGS. 2c, 2d, and 8. Each of the heater elements or wires 140 and 142 is preferably 175 long, formed in coils 40.5 feet long and made of what is known by the trade name of #12 Jeluff Alloy "K" wire. The heater elements 140 and 142 are connected in parallel and each is grounded electrically to the supporting frame 114. This circuit arrangement provides a heater resistance of 11 ohms and has
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A rating of approximately 16 kw. at 440 volts at a rating for the wire of 15 Watts per square inch surface area.

The electrical circuit of the heater may be more clearly seen in FIG. 3 of the drawing. A suitable power source, which may be, for example, a 480 volt single phase 60 cycle per second source, is connected to a primary winding 150 of a power transformer 151 which has a secondary winding 152 grounded at its mid-point. The secondary winding 152 is connected across a coil 153 to which with first and second variable taps 156 and 158 respectively, form an autotransformer 155 for supplying an adjustable voltage between the power conductors 17 and 19 connected to the two heater elements 140 and 142.

A temperature indicating device 160 which may be of any conventional type is connected to the thermistor 76 located in the cable cross-over 34 and also to each of the thermocouples 29, 30, 31 and 33. A balancing network 162 which may be, for example, any suitable known bridge arrangement is selectively coupled through a three-position switch 164 having a movable arm m and three a, b, and c, to one of the three thermocouples 30, 31 and 33 located in the heating section 27 of the heater housing 18. The balancing network 162 is also coupled to a potentiometer 166 which has two fixed terminals 167 and 170 and an adjustable tap 172. A first reversible motor 174 is electrically controlled by the balancing network 162 and is mechanically coupled to the adjustable tap 172 of the potentiometer 165. A marker (not shown) of a strip-chart recorder 167 is fitted on the tap 172 of the potentiometer 166 so as to produce a graph 176 on a strip-chart 178 of the recorder 167 to provide a record of the borehole temperature thereon. The strip-chart 178 is driven at a uniform speed by the chart drive motor 182.

A movable contact 184 is mounted on the tap 172 of potentiometer 166 so as to be electrically insulated therefrom. First and second electrical contacts 186 and 188 are disposed at fixed spaced apart points so as to be electrically contacted by the movable contact 184 at various time intervals. The first electrical contact 186 is connected directly to one terminal of a first 110 volts, 60 cycle per second source 191 and the second electrical contact 188 is connected to the other terminal of the first 110 volt source 191 through a protective resistor 190. A relay 192 has a coil 194 connected between the second electrical contact 188 and the movable contact 184. The relay 192 also has a first fixed contact 196 and a cooperating first movable arm 198 normally in an open position and second and third fixed spaced apart contacts 200 and 202 and a cooperating second movable arm 204 normally contacting the third fixed contact 202. The first movable arm 198 is electrically connected to the movable contact 184 and the first fixed contact 196 is connected to the first electrical contact 186. A second 110 volt, 60 cycle per second source 193 has a first terminal connected to a first terminal 205 of second motor 206. A second terminal of the second 110 volt source 193 is connected through the second movable arm 204 and the third fixed contact 202 of the relay 192 and through a normally closed motor switch 208 to a second terminal 209 of the second reversible motor 206. A third terminal 210 of the second reversible motor 206 is connected through a second normally closed motor switch 212 to the second fixed contact 208 of the relay 192. A motor switch actuating arm 214 is mounted on the first variable tap 156 of the autotransformer 155 to open the first and second motor switches 208 and 212 when the desired voltage limits between the variable taps 156 and 158 are reached. The variable taps 156 and 158 of the autotransformer 155 are mechanically coupled to the second reversible motor 206. The first motor switch 208 is disposed in cooperation with the actuating arm 214 so as to provide a lower voltage limit for the heater elements 140 and 142. The second motor switch 212 is disposed in cooperation with the actuating arm 214 so as to provide an upper voltage limit for the heater elements 140 and 142.

In operation the electrical heater elements 140 and 142 may be assembled within the heater housing 18 at any convenient location but preferably without connecting thereto the power and signal cables 26 and 28 which may be done at the well site. The temperature indicating device 160, the strip-chart recorder 167, the balancing network 162, the relay 192 and the first and second reversible motors 174 and 206 may be installed in a van-type truck for ease of operation and protection from the elements. At the well site the necessary length of the insulation coated power cable 26, for example, a Tufon cable, is connected to the power leads 17 and 19 in the heater head 24. The heater head 24 is then attached to the heater housing sheath 20 and the interior of the heater housing 18 is pressurized through valve 86 located in the support block 84 to approximately 200 p.s.i.g. to protect the housing 18 from high borehole pressure. The power and signal cables 26 and 28 and the chain 72 are taped or tied together and threaded through successive joints of the protective tubing 32 for approximately 200 feet and, preferably, the number of feet necessary to prevent the cable cross-over 34 from being immersed in the borehole liquid. The heater housing 18 and its contents are then placed in the borehole and the protective tubing 32, with the cables enclosed, is made up into a string as the heater housing 18 is lowered into the well. The cable cross-over 34 through which the cables 26 and 28 pass from inside to the outside thereof is then connected to the upper end of the protective tubing 32 and this section of the string is pressurized through the valve 25 in the cross-over 34 to approximately 200 p.s.i.g. to insure against collapsing of this section during normal operations when the annular pressure is about 300 p.s.i.g. or higher.

The perforated pup-joint 38 is next placed in the string to allow the well bore to be flushed from the bottom upward with gas, for example, carbon dioxide, prior to pulling the heater from the borehole following the completion of the in situ combustion operation. Successive joints of well tubing 36 are then made up in the tubing string with the cables 26 and 28 banded or tied to the string by ties 21, preferably, at each joint, until the heating section 27 of the heater housing 18 is lowered to a total depth adjacent to the formation to be treated, as shown in FIG. 1 of the drawing.

The braden head 16 of the well 10 is installed with the cables 26 and 28 passing therethrough and packed off pressure tight. The power cable 26 is connected to the autotransformer 155 and the signal cable 28 is connected to the temperature indicating device 160 and two of the conductors of the signal cable 28 are also connected to the balancing network 162 to one of the three thermocouples 30, 31 and 33 in the heating section 27 through the three-position switch 164.

With the down hole equipment in place, an air compressor (not shown) is operated to force air through the pipe 42 into the annular space between the well casing 14 and the outside of the strings of tubing 32 and 36. The air may be injected into the well through the pipe 42 at a relatively high initial pressure to remove the borehole fluid and then reduced by a substantial amount. The voltage is then applied to the power cable 26 to supply energy to the heater elements 140 and 142. The operation of the present invention has been so designed that, if desired, full load may be applied to the heater elements 140 and 142 at any time without regard to a thermal gradient.

The temperature indicating device 160 continuously and simultaneously indicates the temperature of five lon-
gitudinally spaced points in the borehole, at the thermistor 76 which provides indications of the temperature in the heater head 24 and at the thermocouples 30, 31 and 33 which provides indications of the temperature at the upper, middle and lower portions, respectively, of the heating section. The temperature detected by one of the thermocouples 30, 31 or 33 may be recorded in the strip-chart recorder 167 by placing the movable arm \( m \) in contact with one of the stationary contacts \( a, b \) or \( c \), respectively, of the three-position switch 164. As shown in FIGURE 3 of the drawing, the movable arm \( m \) is in contact with fixed contact \( b \) of the three-position switch 164 so that a record will be provided of the temperature detected by the thermocouple 31 located in the middle portion of the heating section 27. Thus, the voltage produced by the thermocouple 31 will be applied to the balancing network 162. The potentiometer 166 has a constant voltage applied to the two fixed terminals 168 and 170 to produce a range of voltages which may be used to balance the voltage produced by the thermocouple 31. The required voltage to balance the measuring network 162 is derived from the adjustable tap 172 of the potentiometer 166, the portion of which is adjusted by the first reversible motor 174. When the balancing network 162 is in equilibrium the first motor 174 is stationary, but when the voltage produced by the thermocouple 31 increases, the unbalanced condition will cause the first motor 174 to move the tap 172 in one direction until a balancing voltage is reached, and when the voltage produced by the thermocouple 31 decreases, the unbalanced condition will cause the first motor 174 to move the tap 172 of the potentiometer 166 in the opposite direction until a balancing voltage is reached, so as to again produce an equilibrium condition in the balancing network 162 at which time the first reversible motor 174 ceases to drive the adjustable tap 172. Since the position of the tap 172 of the potentiometer 166 is an indication of the temperature in the middle portion of the heating section 27, a marker mounted on the tap 172 of the potentiometer 166 produces a graph 176 on the strip chart 178 of the recorder 177.

In order to control the temperature range within which the heater elements 140 and 142 are to operate the first and second electrical contacts 168 and 188 are positioned at spaced apart points so as to cause an increase in the voltage applied to the conductors 17 and 19 of the power cable 26 when the temperature in the heating section 27 falls to the minimum desired temperature and to cause a decrease in the voltage applied to the conductors 17 and 19 of the power cable 26 when the temperature in the heating section 27 reaches the desired maximum temperature. When the desired maximum temperature is produced in the heating section 27 the movable contact 184 mounted on the tap 172 is in electrical contact with the second electrical contact 188 which shorts out the coil 194 of the relay 192. With the coil 194 shorted the second movable arm 204 contacts the third fixed contact 202 of the relay 192 to complete the circuit from the second 110 volt source 193 through the first normally open second motor switch 208 to the second terminal 209 of the second reversible motor 206. The variable tap 156 which carries the actuating arm 214 of the autotransformer 155 is then driven to the right as illustrated in FIGURE 3 of the drawing to decrease the voltage between the first and second variable taps 156 and 158 and thus between conductors 17 and 19 of the power cable 26. The first variable tap 156 will continue to move toward the right until the actuating arm 214 opens the first motor switch 208 thus to provide the minimum voltage applied to the conductors 17 and 19 of the power cable 26. The decrease in voltage in the conductors 17 and 19 produces a decrease in the amount of energy supplied to the heating section 27. This will tend to cause a decrease in the temperature in the heating section 27 and thus the first reversible motor 174 in response to the output from the balancing network 162 will drive the tap 172 of the potentiometer 166 toward the first electrical contact 186. When the tap 172 reaches the point on the potentiometer 166 corresponding to the desired minimum temperature the movable contact 184 will contact the switch 186 to energize the coil 194 of the relay 192. When the coil 194 is energized the first movable arm 198 contacts the first fixed contact 196 which continues to connect the coil 194 to the first 110 volt source 193 even after the movable contact 184 has been disconnected from the first electrical contact 186. When the coil 194 is energized the second movable arm 204 of the relay 192 is in contact with the second fixed contact 200 of the relay 192. With the movable arm 204 contacting the second fixed contact 200 the second 110 volt source 193 is connected through the second normally closed motor switch 212 to the third terminal 210 of the second reversible motor 206. The variable taps 156 and 158 of the autotransformer 155 will now move toward the left as illustrated in FIGURE 3 of the drawing until the actuating arm 214 on the variable tap 156 opens the second motor switch 212 thus to provide the maximum voltage applied to the two conductors 17 and 19 of the power cable 26. This maximum voltage will be applied continuously to the heating elements 140 and 142 until the desired maximum temperature is reached in the heating section 27 at which time the movable contact 184 will contact the second electrical contact 188 as shown in FIG. 3 of the drawing to short circuit the coil 194 of the relay 192 to again place the second movable arm 204 in contact with the third fixed contact 202 of the relay 192 to cause motor 206 to drive the first and second variable taps 156 and 158 of the autotransformer 155 toward the right in the direction which decreases the voltage applied to the conductors 17 and 19 of the power cable 26. This operation is repeated for any desired length of time.

In one well in which an in situ combustion operation was performed with the heater of the present invention, an initial pressure of 680 p.s.i.g. was maintained in the well for about one hour after which time the pressure was decreased to 500 p.s.i.g. at which level it was held constant for five hours. During this period of time, the fluid in the well bore was displaced into the subsurface formations. The air injection rate during this period was about 340,000 cubic feet per day. After about two days of operation, the air injection rate was reduced and varied between about 150,000 to 200,000 cubic feet per day for the remainder of the in situ combustion operation.

The electrical power to the heater was turned on and increased over a period of ten hours to a load of 30 volts and 28.2 amperes, with a recorded temperature of approximately 870° F. After the borehole temperature reached approximately 870° F, the temperature in the well bore increased without an increase of power input to the electrical heater. The power to the heater was then turned on and increased to about 1,350° F and then gradually decreased over a period of about three hours to approximately 950° F. At this point the power was again turned on and gradually increased to 440 volts and 33.5 amperes where it remained for about 120 hours, i.e. until the in situ combustion operation was completed.

Although in the above-mentioned in situ combustion operation of one well the heater operated at 950° F. for a period of 120 hours, it has been successfully operated at higher temperatures for longer periods of time and is capable of sustained operation at 1,500° F.

Accordingly, it can be seen that an improved heater for the recovery of petroleum by thermal methods has been provided. Furthermore, the invention has provided a heater which is easily positioned in a borehole by the use of standard oil field supplies ordinarily found at a
well site which eliminates the need for expensive armored multi-conductor cables.

Obviously, many modifications and variations of the invention as hereinabove set forth may be made without departing from the spirit and scope thereof and therefore only such limitations should be imposed as are indicated in the appended claims.

We claim:

1. An electrical borehole heater comprising in combination an elongated heater housing having a heating section below a heat baffle section, an electrically resistive element located in said heating section, a support frame for said element disposed within said housing, said frame extending longitudinally over the length of both said heating and heat baffle sections, said frame comprising elongated flat plates disposed transversely along a longitudinal axis to form a cruciform cross-section, a plurality of openings in said frame located in said heating section and near the longitudinal exterior edges of said plates, a plurality of annular insulators for supporting said resistive element and adapted to be inserted in said openings, electric circuit means in said housing for supplying electrical energy to said resistive element, and means for suspending said housing at a predetermined location in a borehole.

2. An electrical borehole heater as set forth in claim 1 wherein said electrically resistive element is wound in the form of a first helix of a first constant radius which first helix is wound in the form of a second helix of a second constant radius substantially greater than the first radius, and the internal diameter of each of said annular insulators is substantially equal to the external diameter of the first helix.

3. An electrical borehole heater as set forth in claim 1 wherein said suspending means includes a string of protective tubing connected to the upper portion of said heater housing coaxial therewith, and wherein said electric circuit means includes a power cable disposed within said protective tubing, said string of protective tubing including means for providing a fluid-tight seal between the interior and exterior thereof.

4. An electrical borehole heater as set forth in claim 3 further including means disposed within said protective tubing for supporting said power cable.

5. An electrical borehole heater as set forth in claim 4 wherein said supporting means includes a chain and a plurality of longitudinally spaced ties attaching said power cable to said chain.

6. An electrical borehole heater as set forth in claim 1 further including temperature responsive means for controlling the flow of electrical energy to said resistive element.

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