

Sept. 5, 1967

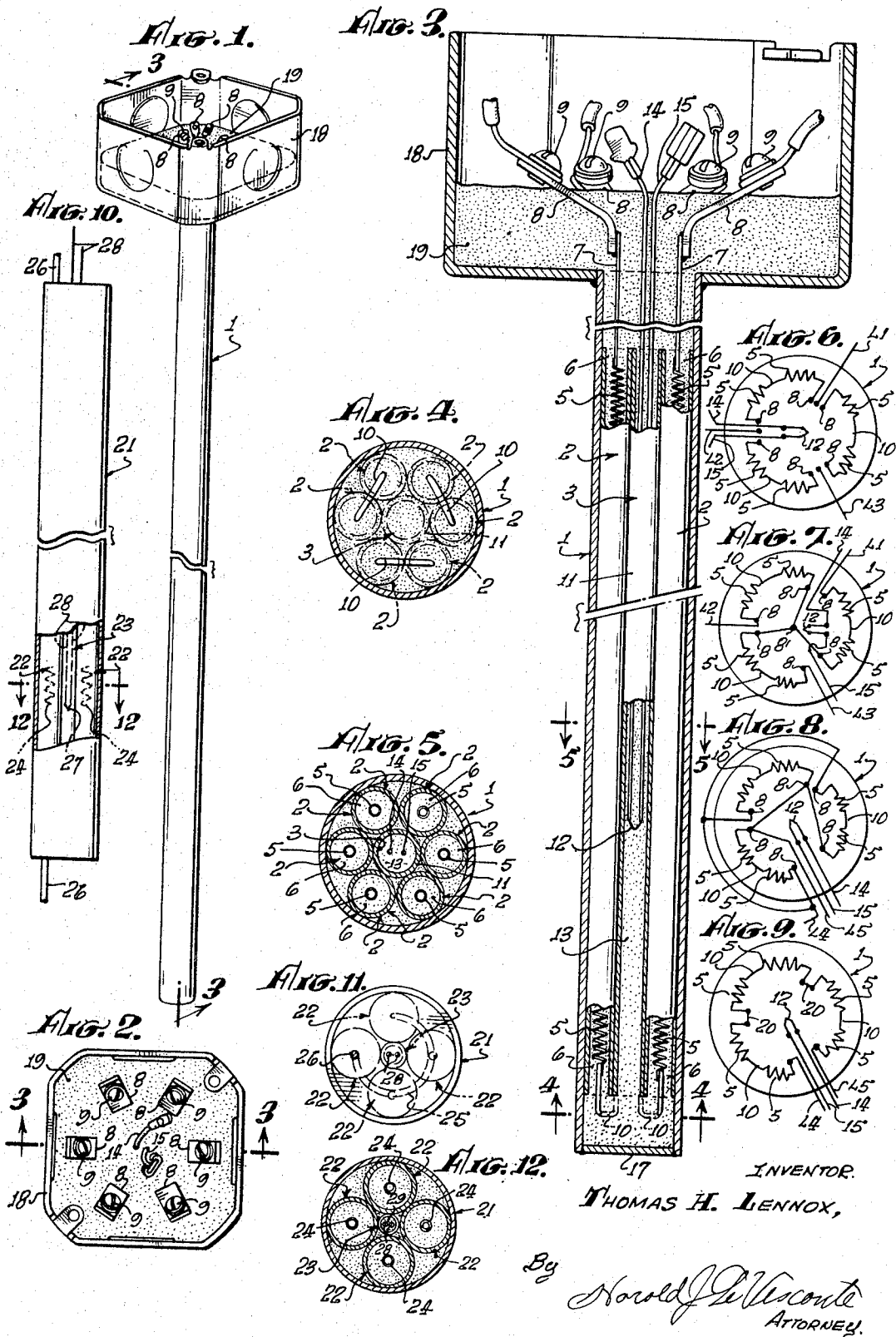
T. H. LENNOX

3,340,382

MULTI-CELL ELECTRICAL HEATER

Filed May 3, 1965

4 Sheets-Sheet 1



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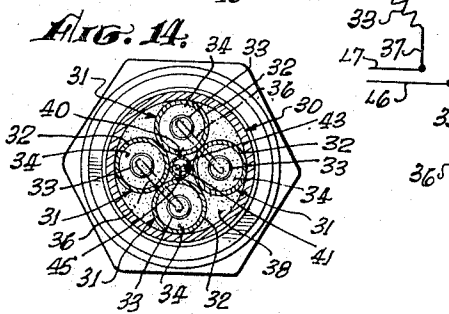
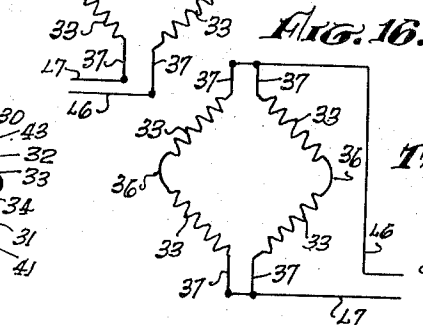
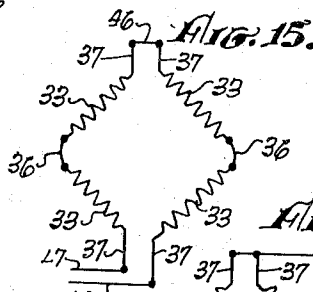
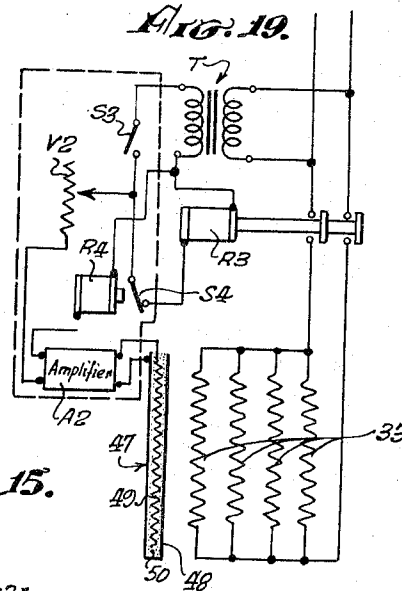
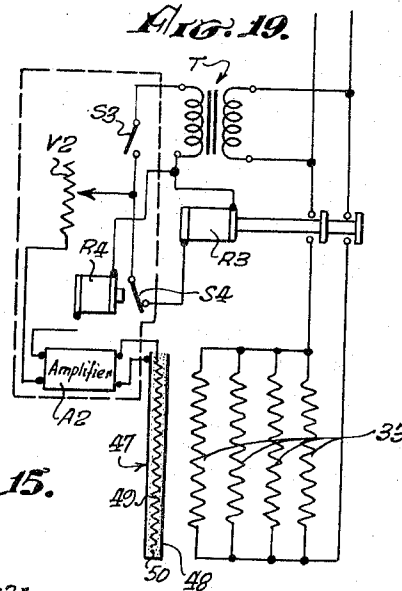
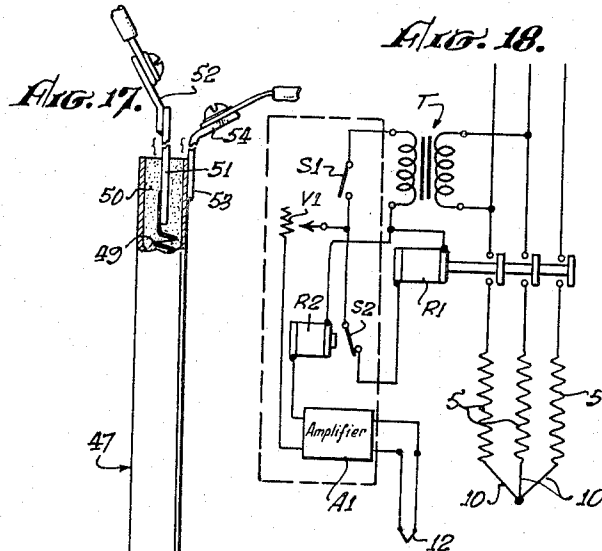
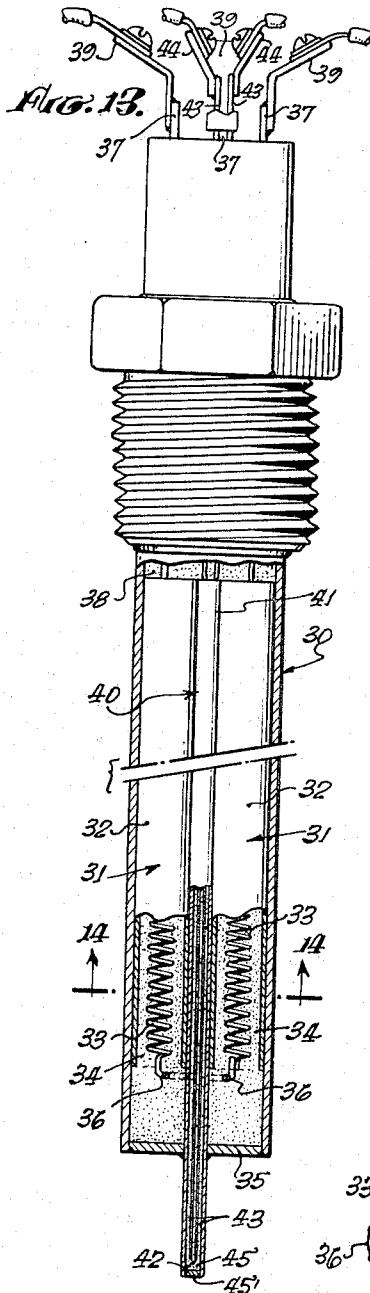
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MULTI-CELL ELECTRICAL HEATER

Filed May 3, 1965

4 Sheets-Sheet 2



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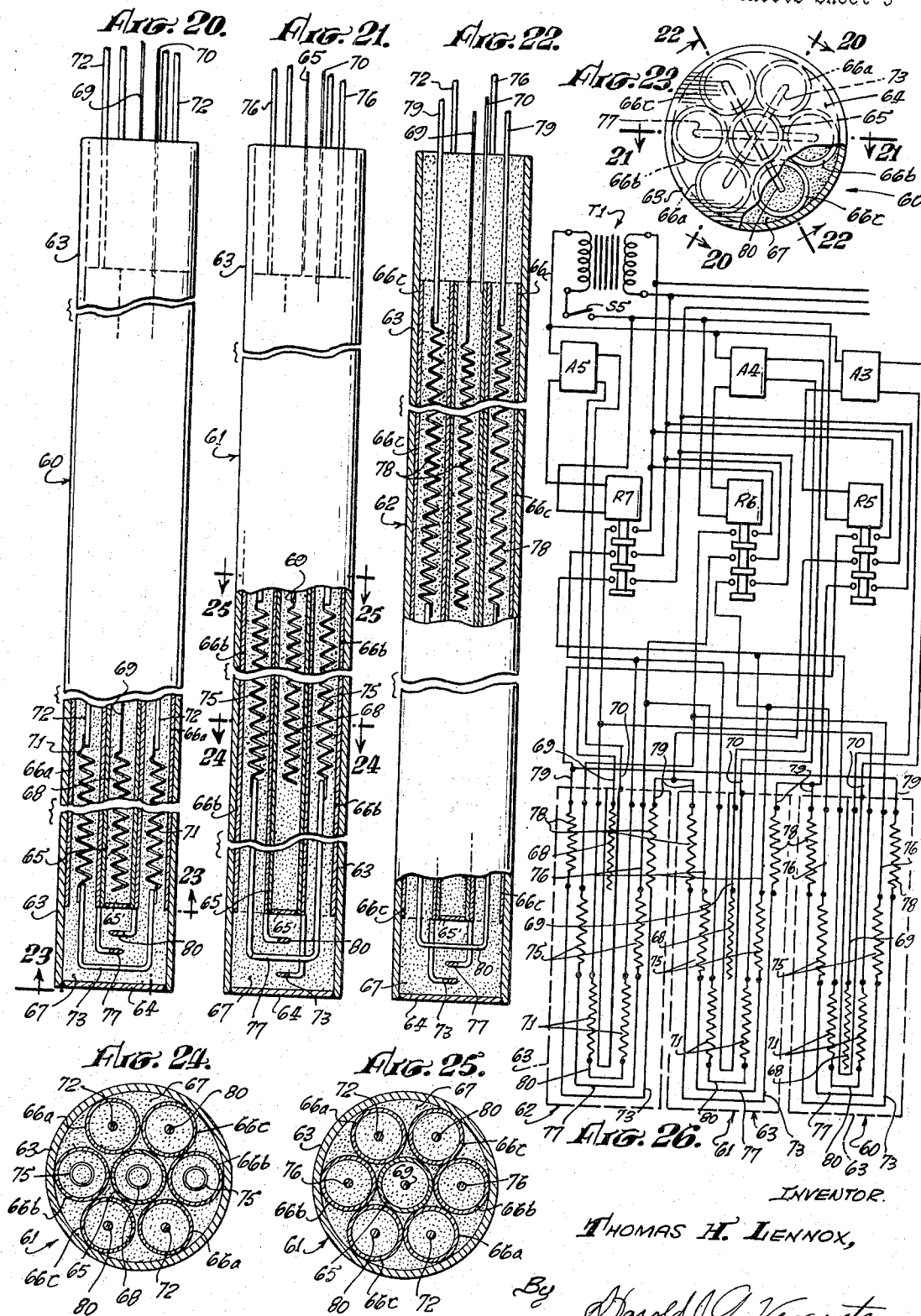
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3,340,382

MULTI-CELL ELECTRICAL HEATER

Filed May 3, 1965

4 Sheets-Sheet 3



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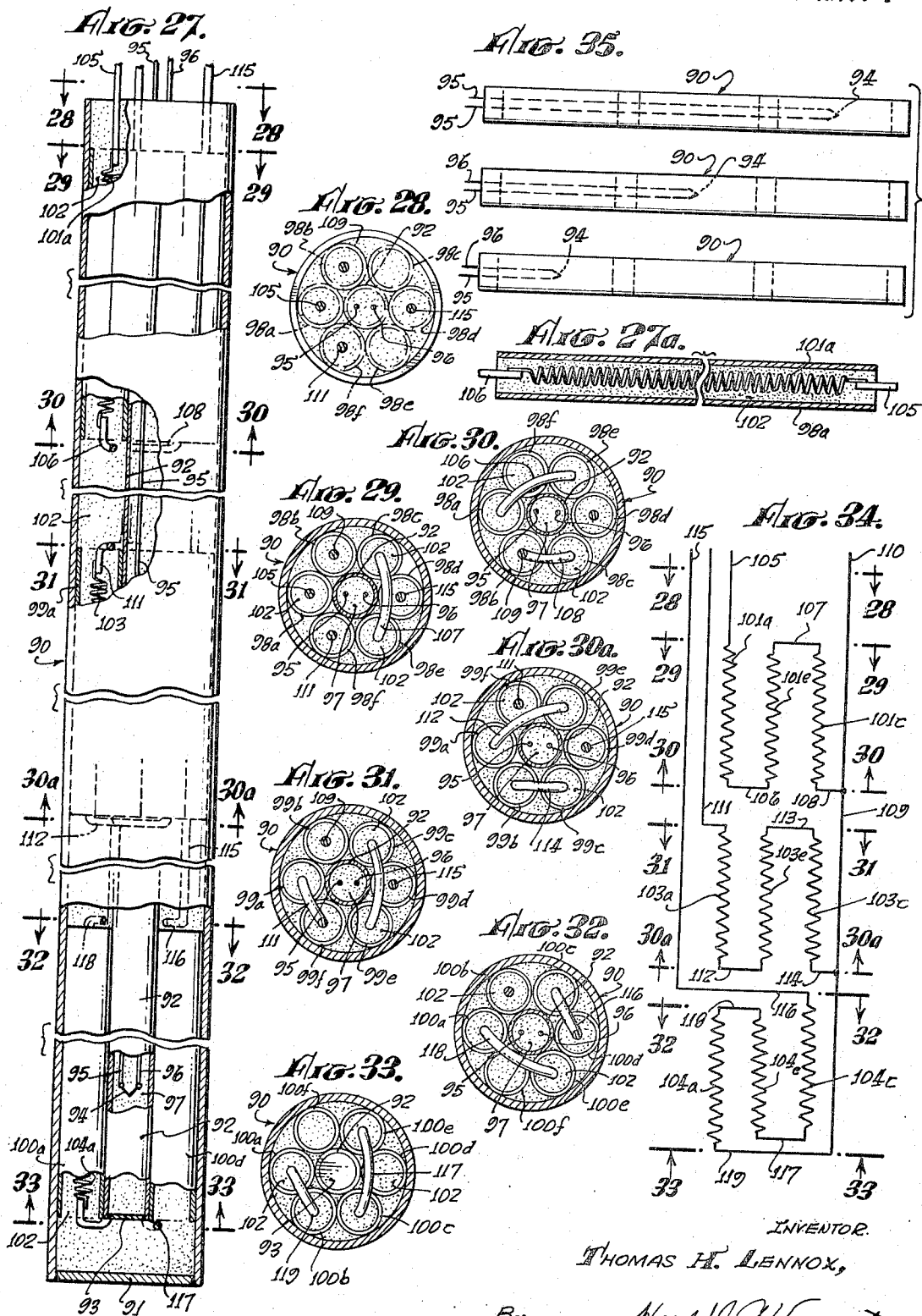
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3,340,382

MULTI-CELL ELECTRICAL HEATER

Filed May 3, 1965

4 Sheets-Sheet 4



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3,340,382

MULTI-CELL ELECTRICAL HEATER

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Filed May 3, 1965, Ser. No. 452,649
15 Claims. (Cl. 219-544)

This invention relates to electrical resistance heaters and more particularly to a form thereof characterized by increased output for a given size of envelope as compared with prior art heaters having a comparable wattage output.

An object of the present invention is to provide a resistance heating device comprising an elongated metal casing having a plurality of resistance heating elements extending therein in parallel relation to one another.

Another object of the invention is to provide an electrical heating apparatus of the foregoing type having the sensor component of a control means embodied therein.

A further object of the invention is to provide an electrical heating device including a plurality of separate resistance heating elements each separately contained in a metal tube and secured therein by compacted MgO with the said individual tubes being secured in an enclosing larger tube by a second body of compacted MgO.

Still another object of the invention is to provide a plural element heating device embodying any of the foregoing objects and in which the elements are internally interconnected and include exterior terminal means capable of being connected with a source of energy in a plurality of different circuit arrangements.

With the foregoing objects in view, together with such additional objects and advantages as may subsequently appear, the invention resides in the parts, and in the construction, combination and arrangement of parts described, by way of example, the following specification of certain presently preferred embodiments of the invention, reference being had to the accompanying drawings which form a part of said specification and in which drawings:

FIG. 1 is a perspective view of a first embodiment of a resisting heating device in which the present invention is incorporated, an intermediate portion of the device being broken away to conserve space,

FIG. 2 is a terminal end view of the device shown in FIG. 1,

FIG. 3 is a longitudinal medial sectional view taken on the line 3-3 of FIGS. 1 and 2, portions of the exposed parts being further broken away to disclose details of interior construction,

FIGS. 4 and 5 are transverse sectional views taken respectively, on the lines 4-4 and 5-5 of FIG. 3,

FIGS. 6, 7, 8 and 9 are circuit diagrams of different circuit arrangements possible with the device shown in the preceding figures,

FIG. 10 is a side elevational view, with an intermediate portion broken away, of another embodiment of the principles of the invention characterized principally by the disposition of the terminals for connection with the power source at both ends of the heater,

FIG. 11 is a top plan view of FIG. 10 having reference only for the position of the heater shown in that figure,

FIG. 12 is a transverse sectional view taken on the line 12-12 of FIG. 10,

FIG. 13 is a side elevational view, partly in section of a second embodiment of the invention, said embodiment being characterized by a different mounting means and by a different arrangement of the temperature sensor means associated therewith, an intermediate portion of the device being omitted to conserve space,

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FIG. 14 is a transverse sectional view taken on the line 12-12 of FIG. 13,

FIGS. 15 and 16 are circuit diagrams showing the heating elements of the embodiment of the device shown in FIGS. 13 and 14 connected respectively in series and in parallel pairs configuration,

FIG. 17 is a side elevational view partly in section of a heat responsive conductor of the type disclosed in my co-pending application, Ser. No. 364,079, filed May 1, 1964 and usable as an alternative controlling sensor in either of the disclosed embodiments in place of a thermocouple means there shown,

FIG. 18 is a circuit diagram of a typical installation of a first disclosed embodiment and showing the thermocouple sensor as the controlling means,

FIG. 19 is a circuit diagram of a typical installation employing a heat responsive conductor of the type shown in FIG. 14 as the controlling means for a heating device constituting the embodiment shown in FIG. 10,

FIGS. 20 through 35 illustrate another application of the principles of the invention in which the heater coils are of less length than the surrounding sheath and are arranged in axial alignment therewith and are separately connected to the source of energy. In these figures:

FIG. 20 is a side elevation of a heater assembly having a terminal end and a closed end, intermediate portions of the heater assembly being broken away to conserve space, and the group of heating elements and a sensor disposed adjacent the closed end being shown in medial longitudinal section,

FIG. 21 is a view somewhat similar to FIG. 20 but showing an intermediate group of heater elements and the associated sensor, the heating elements, sensor and closed end of the heater assembly being shown in medial longitudinal section as on the line 21-21 of FIG. 23,

FIG. 22 is a view similar to FIGS. 20 and 21 but showing a group of heater elements and having an associated sensor disposed adjacent the terminal end of the heater assembly and the closed end of the heater assembly shown in medial section as on the line 22-22 of FIG. 23,

FIG. 23 is a bottom plan view, partly in section, of FIG. 20,

FIG. 24 is a transverse section across the heater elements and sensor as, for example, on the line 24-24 of FIG. 21,

FIG. 25 is a similar section taken between longitudinally spaced groups of heater elements and sensor as on the line 25-25 of FIG. 21,

FIG. 26 is a circuit diagram of the three heater assemblies shown in FIGS. 20, 21 and 22 connected to a single source of energy and arranged with separate controlling means for the corresponding groups of heating coils in all three heater assemblies,

FIG. 27 is a side elevational view of a heater assembly having a closed end and a terminal end and cross connected groups of heater elements disposed in shorter tubes contained within the sheath at spaced longitudinal distances,

FIG. 27a is a medial sectional view of one of the heater tube elements, an intermediate portion being omitted to conserve space,

FIG. 28 is a terminal end view of the heater shown in FIG. 27,

FIGS. 29, 30, 30a, 31, 32 and 33 are, respectively, enlarged scale transverse sectional views taken on the lines 29-29, 30-30, 30a-30a, 31-31, 32-32 and 33-33 of FIG. 27,

FIG. 34 is a circuit diagram of the circuitry within the heater assembly shown in FIG. 27, and

FIG. 35 is a semi-diagrammatic view of three heater as-

semblies such as shown in FIG. 27 with the heat sensor devices thereof disposed, respectively, with different groups of the heating coil groups in the manner taught in FIGS. 20, 21 and 22.

Referring to the drawings and particularly to FIGS. 1-9, there is shown a first embodiment illustrative of the principle of the invention comprising an outer tube or sheath 1 which may be either a single tube, or if extreme heat is involved, as for example, in excess of say, 1500° F. this tube may be of a construction disclosed in my co-pending application, Ser. No. 354,070, filed Mar. 23, 1964, now Patent No. 3,305,820, and comprising an inner tube of mild steel and a closely fitting outer tube of a chromium containing alloy such as, for example, Inconel or an equivalent thereof. The length of this tube may be such as will serve the intended use and may be from, say, one foot, to forty feet or even more. Disposed within the sheath 1 is a series of six separate heater assemblies 2 surrounding a centrally disposed sensor assembly 3. Each heater assembly comprises a metal tube 4 carrying a centrally disposed, helically arranged resistance element 5 embedded therein in a compacted mass 6 of MgO. The heater tubes 4 are of less length than the casing 1 and terminate within the ends of said casing. At one end thereof the ends of the resistance elements are connected to leads 7 which extend beyond the adjacent end of the casing 1 and are connected to terminals 8 having screws 9 by which power leads L may be connected thereto. At their opposite ends, the resistance elements 5 are connected in pairs by three leads 10.

The heater assemblies 2 surround and contact the sensor assembly 3 here shown as a metal tube 11 having a thermocouple element 12 disposed therein in a compacted mass 13 of MgO. The sensor tube 11 is preferably of the same length as the heater tubes and the leads 14 and 15 extending to the thermocouple element 13 project beyond the same end of the casing 1 as the leads 7. The heater assemblies and the sensor assembly are first assembled in the casing and the casing is then filled with uncompacted MgO powder and is subjected to a swaging process thus effecting a tight metal to metal contact between the casing and the heater tubes and between the heater tubes with each other and with the sensor assembly tube while the compacted MgO between the tubes and surrounding the leads beyond the end of the heater and sensor tubes imparts rigidity to the entire device and serves to prevent the contact of air with the metal surfaces within the casing which are subjected to heat within the device whereby the clean metal to metal contacts are preserved unoxidized for efficient heat conduction. The end of the casing 1 remote from the terminals is closed by an end cap means 17 welded in place and which will be of the same single or two-ply composition as the casing wall. The lead end of the device may be any desired form, the illustrated form being that of a terminal box 18 welded to the end of the casing into which the terminals extend in a diverging pattern, the box being partially filled with a suitable ceramic material mass 19.

FIGS. 6-9 show the alternative forms of circuitry which may be employed with this embodiment of the invention; FIGS. 6 and 7 showing alternate 3-phase circuits and FIGS. 8 and 9 showing single phase circuits. In FIG. 6 the power lines L1, L2 and L3 are attached, respectively, to adjacent pairs of the terminals 8 forming a delta connected circuit. In FIG. 7, the leads L1, L2 and L3 are connected to one of the terminals 8 of each pair of heating elements formed by the connecting leads 10 while the other leads of said pairs are interconnected with each other at 8' to form a Y-connected circuit.

In FIG. 8, one terminal 8 of each pair of connected heater coils is connected in common to one power lead L4 while the other terminal 8 of each pair of heater coils is connected in common to another power lead L5 thus connecting the pairs of heaters in parallel relation. In FIG. 9, the power lead L4 is connected to one of the

terminals 8 of a pair of heater coils and the other lead L5 is connected to the adjacent terminal 8 of the said pairs of heater coils and the other adjacent terminals 8 are interconnected by bus bar means 20 so that all of the heater coils are connected in series. In each case, the circuit of the thermal responsive sensor component is separate from the power circuit so far as the circuitry of the device, per se, is concerned and the tube within which the sensor element is contained serves also to hold the heater tubes tightly against the inner face of the casing wall.

FIGS. 10, 11 and 12 are presented to show (a) that the invention is not limited to heaters having the terminals thereof at one end only and (b) that the number of tubes containing the heating coils may be any number which may be encompassed by the exterior sheath. In this embodiment the sheath 21 is open at both ends and surrounds a series of four heater assemblies 22 which are of slightly lesser length than the sheath and which, in turn surround a sensor assembly tube 23. The heater coils 24 at the ends of the tubes are connected to each other by bus bar members 25 which project through the mass of compacted MgO with the ends of the sheath 21 to form terminals 26 thus connecting all of the heater coils in parallel. Obviously, if desired, by the use of an odd number of heater assemblies or the equivalent thereof, the heater assemblies could be interconnected in series relation with each other as will be evident from an examination of any one set of coils in FIG. 34. The sensor assembly tube carries a thermocouple 27 connected to leads 28 packed in a mass of compacted MgO 29 with the leads extending from one end only of the sheath, it being obvious that the leads could, if desired, extend one each from each end of the sheath.

Referring next to FIGS. 13, 14, 15 and 16, there is shown a second embodiment of the invention differing from the first embodiment in that (a) the number of heater assemblies is different, (b) the mounting and terminal means are different, and (c) the thermally responsive sensor is arranged to respond to changes in the temperature of the medium being heated rather than of the heating device, per se. It is to be understood as will be explained in more detail hereinafter, that any of the different features of the second embodiment may be substituted for corresponding features in the first embodiment and vice versa. It is preferred that for any given number of heating assemblies within the casing that each heating assembly tube in contact with the adjacent heating assembly tubes, with the sensor assembly tube and with the interior wall of the casing so that complete metal to metal contact exists throughout the entire assembly of the device.

Specifically, the second embodiment of the invention comprises an outer tubular sheath 30 which, as in the case of the casing 1, may be either of single ply or two-ply construction. Disposed within the sheath 30 are four heater assemblies 31 each comprising a metal tube 32 of less length than the sheath 30 and containing a helical resistance element 33 embedded therein in a mass 34 of MgO. The ends of the heater resistance elements 33 adjacent the casing end cap 35 are connected in pairs by leads 36, 36 and the opposite ends of each heater coil is connected to an equal number of leads 37 which extend beyond the end of the heater tube through the mass 38 of MgO in which the heater tubes are embedded in the sheath and which exteriorly of said mass carry terminals 39 for connection to power leads in various circuit arrangements to be hereinafter described.

Disposed centrally between the heater assembly tubes and being contacted by each of them is the sensor assembly 40 comprising a metal tube 41 having a thermocouple element 42 therein and leads 43, 43 extending from said thermocouple element out of the terminal element of the heater sheath to terminals 44, 44, the said leads and thermocouple being embedded in said tube in a mass 45 of MgO. In the illustrated embodiment, the tube

41 extends through the end cap 35 of the casing so that the thermocouple element is disposed beyond the end of the sheath 30 and is responsive to the temperature of the medium in which the heater device is immersed. An end cap 45 closes the end of the sensor tube. It will be obvious that this sensor assembly 40 may terminate within the casing as in the first embodiment of the invention or that the corresponding element of the first embodiment may extend out beyond the end cap thereof as here illustrated.

FIG. 15 shows a circuit diagram in which one terminal 37 of each of the pairs of heater elements of this embodiment of the invention are interconnected as at 46 while the other two terminals 37 are connected, respectively, to one each of a pair of power leads L6 and L7, thus connecting the heater resistance elements in series. In FIG. 16 the diagram shows the power lead L6 connected to one of the terminals 37 of each pair of resistance elements while the power lead L7 is similarly connected to the other terminals of the two pairs of resistance elements, thus connecting the two pairs of resistance elements in parallel.

Next referring to FIG. 17, there is shown an alternative form of temperature sensor 47 adapted to be used in the present invention as a substitute or alternative for the illustrated thermocouple type of elements. This sensor is similar in mode of operation to that disclosed in my co-pending application, Ser. No. 364,079, filed May 1, 1964, and comprises a metal tube 48 having a helically formed conductor 49 capable of withstanding high temperatures centrally disposed therein and embedded in a mass 50 of MgO of a grade having impurities which give it a known electrical conductivity when heated to a predetermined temperature. The conductor is connected at one end only thereof to a lead 51 ending in a terminal 52 disposed in the same general area as the terminals for the heater elements. A lead 53 also extends from the tube 48 to a terminal 54 also disposed in close proximity to the other terminals, the leads 51 and 53 being of such length as will extend through the mass of MgO between the ends of the heater and sensor tubes and the end of the sheath 30.

The operation of this sensor is described in the said co-pending application and will be only briefly mentioned here. A current of predetermined voltage is impressed on the conductor 49 and is of such magnitude as not to be conducted to the metal tube 48 until the MgO mass 50 interposed between them is rendered sufficiently conductively by the imposed temperature. Upon reaching that temperature, a current flow is established through the sensor completing a control circuit presently to be described with resultant opening of the power circuit until such time as the temperature drop of the MgO mass 50 interrupts the control current.

FIG. 18 is a circuit diagram of a typical circuit arrangement for the first embodiment of the invention, the heaters being as connected in a Y-circuit for operation by 3-phase current. In this arrangement, the primary winding of the transformer T is connected to the appropriate two of the power leads. The secondary winding of the transformer T is connected to the operating coil of a normally open relay R1 controlling the power supply to the heaters. The control circuit for said relay includes a manually operable switch S1 and the normally closed contacts S2 of a relay R2. One side of the operating coil for the relay R2 is connected to amplifying means A1 which is also connected to the thermocouple means 12 and in response to variations in the thermally induced current in the thermocouple means, varies the current supplied to the operating coil of the relay R2 as the supplied current may have been initially varied by the adjustment of the variable resistance V1. The other side of this relay coil is connected to complete the circuit therethrough as to a lead extending between the transformer secondary and the operating coil of the relay R1.

It will be obvious that when the manual switch S1 is closed, the relay R1 will be actuated to close the power circuit to the heater coils until such time as heat developed by the heater induces sufficient current in the thermocouple 12 to cause the amplifying means A1 to effect actuation of the relay R2 with resultant opening of the switch S2 and consequent interruption of the power supply to the heaters until such time as the temperature drop disables the thermocouple allowing the relay R2 to permit the contacts S2 to close with resultant reactivation of the relay R1 and supply of current to the heater coils.

FIG. 19 is a circuit diagram showing a typical operating and control circuit arrangement when a sensor of the type shown in FIG. 17 is employed, the heater arrangement shown in connection therewith being that of the second embodiment of the invention with the pairs of heater coils connected in parallel as shown in FIG. 16. In this arrangement, the transformer T is connected to a power controlling relay R3 (which in this instance is arranged for single phase current) with an interposed manual switch S3 and the relay operated switch contacts S4 similar to the corresponding circuit in FIG. 18. As in the circuit shown in FIG. 18, one side of the operating coil for the relay R4 is connected to the amplifying means A2 which is also connected to both terminals of the sensor means 47 and which, in response to temperature induced variations in the conductivity of the sensor unit, regulates the current supply to the operating coil of the relay R4 received from the transformer secondary coil and as that supply may have been varied by adjustment of the variable resistance V2. Also as in the first described circuit, the other side of the operating coil of relay R4 is connected to complete the circuit therethrough as by a lead extending to the transformer secondary coil or to a lead extending to said secondary coil.

The operation of this control circuit is in general the same as the previously described circuit. Upon closing the manual switch S3, the relay R3 will close the power supply to the heater coils. When sufficient heat is generated in the heater to cause the flow of current through the MgO mass 50 between the tube 48 and the embedded conductor 49, the control relay R4 opens the contact S4 interrupting the supply of current to the heater coils until such time as the temperature drop on the sensor serves to interrupt the flow of current therethrough at the potential established by the variable resistance V2.

FIGS. 20 through 26 show another mode of employment of the principles of the novel multi-cell heating apparatus of the invention comprising three heater assemblies 60, 61 and 62 each comprising an outer tubular metal sheath 63 having one end closed by a metal cap member 64 and having the various terminals to be later described projecting from the opposite end. Disposed within the casing is a cluster of seven smaller tubes comprising a central, sensor housing tube 65 closed by an end cap 65' and three diametrically opposite pairs of tubes designated at 66a, 66b and 66c, all of said tubes being tightly embedded within the sheath 60 by a mass 67 of tightly compacted MgO. The sensor here shown is the type shown in detail in FIG. 14 but differs in each of the heater assemblies by having the helical coil portion 68 thereof of limited length and disposed at different locations in the respective assemblies as, for example, adjacent the closed end of the tube 65 in assembly 60, at an intermediate position in assembly 61 and adjacent the terminal end of the assembly 62, said coil portions being connected by a lead and terminal portion 69 to the system and the tube 65 being connected to the system by a terminal 70.

The pair of heater tubes 66a in the end portions thereof of adjacent the closed end of each heater assembly each carry a resistance heating coil 71, each of said coils being connected at the ends thereof remote from the closed end of the sheath or casing to one each of a pair of leads 72 extending beyond the terminal end of the sheath and 75 serving as a pair of terminals and the opposite ends of

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said coils are interconnected by a bridging lead 73 disposed between the inner end of the tubes 66a and the end cap 64. The resistant coils and associated leads 72 are embedded in the respective tubes 66a in separate masses of compacted MgO.

The tubes 66b each carry at the intermediate portion thereof a helical resistance heating coil 75 similarly connected to terminals 76, 76 projecting from the terminal end of the casing and having the opposite ends thereof interconnected by a bridging lead 77 spaced from the ends of the tubes, the end cap 64 and the transverse lead 73. Similarly the pair of tubes 66c adjacent the terminal end of the casing each contains a helical resistance heating coil 78, said coils having terminal end leads 79 and having the opposite ends connected by a bridging lead 80 extending along the remainder of the tubes and extending in spaced relation to the tube ends, the casing end cap and the other tube bridging leads 73 and 77.

FIG. 26, by way of example, shows one mode of use of a set of three heater assemblies comprising one each of the heat assemblies 60, 61 and 62 arranged so that the sensors 68 associated with the heating coils 71 in heater assembly 60 controls the supply of power to all of the heating coil 71, the sensors 68 associated with the heating coils 75 in the heater assembly 61 controls the supply of power to all of the heating coils 75, and the sensor 68 associated with the heating coils 78 in heater assembly 62 similarly control the supply of power to all of the heating coils 78. To this end, the leads of a three-phase power supply are connected to one side of each of three power controlling relays R5, R6 and R7. The opposite side of relay R5 is connected by leads to the six heating coils 71 so arranged that closure of the relay contacts effects a delta connection of said coils with the power source. The relay R6 is similarly connected to the six heating coils 75 and the relay R7 is similarly connected to the six heating coils 78.

The leads 69 and 70 of the sensor 68 associated with the heating coils 71 of the heater assembly 60 are connected to one side of an amplifier means A3 which is suitably connected to one side of the secondary coil of a transformer T3 having the primary coil thereof connected to two of the power leads, there being an interposed manual switch S5 in the circuit between the transformer and the amplifier A3 and it being assumed that the amplifying means includes variable resistant means corresponding in function to the variable resistant means V2 of FIG. 19 as well as a relay means corresponding to the relay R4 of said FIG. 19. Other conductor means complete the actuating circuit for the operating solenoid of relay R5 are interposed between the amplifier A3 and the other side of the transformer secondary coil. Obviously, upon closing of the switch S5, and assuming that the heater 60 at the closed end thereof is below operating temperature, the relay R5 will be closed and power will be supplied to all of the heating coils 71 until such time as the heat developed causes a predetermined current to flow through the sensor means associated with those coils with the result that the amplifier means will be caused to open the relay means in the circuit through the solenoid coil of the relay R5 and open the relay R5 until such time as the temperature drop effects a cessation of current flow through the sensor with resultant re-energization of the heating coils 71.

The relay R6 similarly controls the supply of power to all of the heating coils 75 and in the heating assembly 61, the sensor 68 is associated with a pair of heating coils 75. An amplifier means A4 is similarly connected to the transformer T3 and to the leads 69 and 70 of the said sensor as well as to the operating solenoid of relay R6 wherefore, upon closing of manual switch S5, the heating coils 75 of all three heating assemblies will be supplied with current as controlled by the amplifier means A4 and the changes in conductivity of the sensor 68. In the same

manner, the power relay R7 is connected to all six of the heating coils 78 and the sensor 68 of the heating assembly 62 is associated with the two heating coils 78 of that assembly. The relay R7 is controlled by a current supply to the operating solenoid thereof by the associated amplifier means A5 which is connected to the leads 69 and 70 of that sensor 68 and to the secondary coil of the transformer T3.

On closing the switch S5, all of the heating coils will be engaged and as soon as any one sensor is heated to a degree to cause it to be sufficiently conductive, the set of heating coils controlled thereby will be temporarily disabled. It will be borne in mind that despite the shortness of the various sections of the heating assemblies as illustrated, each assembly may have a length from a few inches in length to forty feet or more. This capacity for localized control makes it possible to achieve such results as compensation for localized differences in heat loss and similar factors. Also, while the system is shown as laid out for three-phase current, in the light of the foregoing disclosure, those skilled in the art would be able to connect the set of heating assemblies for single phase operation with the various groups of pairs of heating coils connected together either for operation in parallel or in series relation with each other. Still further, this phase of the invention is not limited to sets of six heat producing coils but the novel heating assemblies can be equally well designed to accommodate other numbers of heating coil components, both circumferentially and longitudinally of the main or other casing of the heater assembly.

Referring finally to FIGS. 27 through 35, the species of the invention there shown illustrates the fact that the tubes surrounding the heating coils need not be coextensive in length with the outer casing but may be arranged in shorter groups disposed in longitudinally spaced relation within the main or outer casing and with leads interconnecting the heating coils contained therein extending transversely of the main casing at points intermediate the length of the main casing. This embodiment, however, retains the multi-cell principle of construction with which the present invention is concerned.

The illustration of this embodiment of the invention comprises an outer tubular metal casing 90 closed at one end thereof by a metal cap 91 and having the various terminals projecting from the opposite end thereof. Centrally disposed within the casing is the sensor containing tube 92 having an open terminal end and an inner end adjacent to the closed end of the casing which is closed by an end cap 93, said tube containing a sensor means here shown as a thermocouple 94 connected to leads 95 and 96, the said thermocouple and leads, as shown in FIG. 35, being located at different points in different heater assemblies as will be later discussed in more detail and the said thermocouple and leads being confined in a mass 97 of compacted MgO within the tube 92.

Tightly interposed between the sensor tube 92 and the inner surface of the casing 90 adjacent the terminal end of the casing 90 is a series of six shorter tubes 98a, 98b, 98c, 98d, 98e and 98f, the subscripts beginning at the right hand side of FIGS. 28 and 29 and continuing clockwise therefrom. Similarly, at the midlength of the casing there is a second group of six shorter tubes 99a-99f tightly interposed between the sensor tube 92 and the inner wall of the casing 90, said second group of tubes being longitudinally spaced from the adjacent end of the group of tubes 98a-98f. The casing also encloses a third group of six of said shorter tubes 100a-100f tightly interposed between the sensor tube 92 and the inner surface of the casing 90 and being spaced both from the end cap 91 and the adjacent ends of the group of tubes 99a-99f. All of the tubes having the same subscript are disposed in axial alignment with each other.

In the following description of the circuitry of the heater assembly shown in these figures and for con-

venience only, the terms "upper," "lower," "above" and "below" will be understood to have reference only to the positions shown in FIGS. 27 and 34 and it will be understood that the illustrated devices may be placed in any desired attitude in use.

The heater tubes are alike in structure and the heater tube 98a shown in medial longitudinal section in FIG. 27a is representative. Each of the tubes 98a, 98c and 98e carry resistance elements comprising helical coils designated 101a, 101c and 101e respectively, said coils being formed of resistance wire embedded in a mass of compacted MgO 102, the ends of the coils being connected at each end thereof to certain leads to be described. Similarly, the tubes 99a, 99c, and 99e carry similarly disposed resistance elements 103a, 103c and 103e embedded therein while tubes 100a, 100c, and 100e carry similarly embedded resistance elements 104a, 104c and 104e.

The upper end of resistance element 101a is connected to a terminal lead 105 and the lower end of said resistance element is connected to one end of a transversely extending lead 106 spaced from the lower ends of the upper tubes and having its other end connected to the lower end of resistance element 101e and the upper end of that resistance element is connected by a lead 107 to the upper end of resistance element 101c and the lower end of that resistance element is connected by a transverse lead 108 to a bus bar element 109 which extends from the lower end of the lower group of heater elements up through the centers of tubes 100b, 99b and 98b to an exposed terminal end 110.

The upper end of resistance element 103a is connected to a terminal lead 111 which extends through tube 98f to a point adjacent the upper ends of the "99" group of tubes and thence extends laterally to connect to the upper end of resistance element 103a. The lower end of resistance element 103a is connected by a transverse lead 112 to the lower end of resistance element 103e and the upper end of the latter resistance element is connected by a transversely extending lead 113 to the upper end of resistance element 103c, the lower end of which is connected by a transverse lead 114 to the bus bar 109.

The upper end of resistance element 104c is connected to terminal lead 115 which extends through aligned tubes 98d and 99d and terminates just above the plane of the upper ends of the "100" group of tubes in a lateral run 116 having the end thereof connected to the upper end of resistance element 104c. The lower end of resistance element 104c is connected by a transverse lead 117 to the lower end of resistance element 104e. A transverse lead 118 connects the upper ends of resistance elements 104c and 104a and a final transverse lead 119 forms the lower end of the bus bar 109 and is connected to the lower end of resistance element 104a.

All of the tubes surrounding either the heater coils or the sensor means are preferably formed of a mild, chrome free, steel or other metal or alloy capable of withstanding the developed heat.

Since various forms of power and control circuits have been disclosed in connection with the other embodiments of the invention, and since the present invention, is concerned with heaters embodying the novel multi-cell principle, it is believed that the said disclosed circuitry is sufficient to teach one skilled in the art all that is necessary to create a circuit system for one or more of the heaters shown in FIGS. 27-35 either embodying a single control means for one or more heater assemblies or for a plurality of control means arranged separately to control one or more of the units constituting a plurality of the novel heater assemblies. Also, while the illustrated embodiment of the invention is shown as having three sets of cells longitudinally spaced along a single casing, it is obvious that such groups may be of any number greater than one and

that the number of heating elements in any one group may be greater or less than the groups of six illustrated. Moreover, the different groups may be composed of resistance elements differing from the elements in adjacent groups or be subjected to currents of different magnitudes whereby different degrees or magnitudes of heat output may be achieved at different points along the heater assembly. Obviously also, the sensor means may be either of the two forms illustrated and described in connection with the previously described embodiments of the invention and may be responsive either to the heat developed within the heater assembly, per se, or be responsive to the heat of the medium being heated by the heater as illustrated for example, in FIG. 13.

Finally, referring generally to the illustrated embodiments of the invention, it will be understood that while the outer casing is shown as being of single ply construction, it may also be formed of two-ply construction as taught by my co-pending application, Serial, No. 354,070, filed Mar. 23, 1964, now Patent No. 3,305,820.

While the foregoing specification and drawings have disclosed, by way of example, certain presently preferred embodiments of the invention and has discussed certain variations thereof, it is not to be inferred therefrom that the invention is limited to the precise details of construction thus disclosed and that the invention includes as well all such changes and modifications in the parts and in the construction, combination and arrangement of parts as shall come within the purview of the appended claims.

I claim:

1. An electric heater comprising an elongated tubular, metallic outer sheath means, enclosing and having metallic contact with a plurality of metallic tubular heater sheaths each containing a resistance heating element embedded in a compacted, non-conductive, mineral mass therein, and a metallic, tubular sheath containing a heat responsive sensor within said outer sheath means and maintained in metallic contact with a least one of said heater sheaths and containing means electrically responsive to heat produced by said resistance heating elements, and terminal means projecting beyond at least one end of said outer sheath means for connecting to appropriate sources of electrical energy.

2. An electrical heater as claimed in claim 1 in which said heater sheath and said sensor containing sheath are embedded in a mass of electrically non-conductive material within said outer sheath.

3. An electrical heater as claimed in claim 1 in which at least two of said resistance heating elements are electrically connected in parallel relation with each other.

4. An electrical heater as claimed in claim 1 in which at least two of said resistance heating elements are electrically connected in parallel relation with each other.

5. An electrical heater as claimed in claim 1 in which said sensor and the sheath therefor extends beyond said outer sheath means for response to the medium being heated by said heater.

6. An electrical heater as claimed in claim 1 in which said outer sheath means encloses at least three of said heater sheaths with the resistance heating elements thereof interconnected adjacent the one end of said outer sheath means remote from the terminal end thereof and the opposite ends of said resistance elements being provided with terminals for connection to a three-phase source of energy.

7. An electrical heater as claimed in claim 1 in which said outer sheath means encloses at least three of said heater sheaths, and in which said resistance heating elements are electrically connected to a first terminal at one end of said outer sheath means and to a second terminal at the opposite end of said outer sheath means.

8. An electric heater comprising an elongated tubular

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metallic outer sheath means enclosing and having metallic contact with a plurality of pairs of parallel heater sheaths each enclosing a resistance heating element of less length than the heater sheath embedded in a mass of compacted, electrically non-conductive mineral, one end each of said resistance heating elements being connected to a separate terminal at one end of said outer sheath means and the opposite ends of each of the resistance elements of each pair being electrically connected, said heater sheaths surrounding and being in metallic contact with a sensor containing tubular metal sheath, the resistance elements of each pair being disposed at a different point longitudinally of said outer sheath means than the resistance elements of another pair thereof.

9. An electric heater as claimed in claim 8 in which the heater sheaths constituting a pair thereof are disposed diametrically opposite each other within said outer sheath means.

10. An electrical heater as claimed in claim 8 in which said heater sheaths and said sensor sheath are embedded within said outer sheath means in a mass of compacted, electrically non-conductive mineral material.

11. An electrical heater as claimed in claim 8 in which said sensor sheath contains means electrically conductively responsive to heat produced by said resistance elements and in which said heat responsive means is disposed in close proximity to a selected one of said pairs of resistance elements.

12. An electrical heater as claimed in claim 11 in which said sensor is provided with terminal means projecting from the same end of said outer sheath means as said heater element terminals for connection to control means for supplying current to said resistance elements.

13. An electrical heater comprising an elongated metallic tubular outer sheath means, a tubular sensor con-

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taining metallic sheath disposed centrally of and spaced from the inner surface of said outer sheath means, and a plurality of groups of tubular metallic heater sheaths of less length than said outer sheath means interposed between and maintaining metallic contact with the inner surface of said outer sheath means and said sensor containing sheath, each of said groups being longitudinally spaced from an adjacent group and at least certain of said heater sheaths containing leads extending from terminals at one end of said outer sheath means and others of said heater sheaths in each of said groups containing electrical resistance means interconnected with each other and with at least two terminals, said sensor containing sheath means electrically conductively responsive to heat produced by said resistance heating elements.

14. An electrical heater as claimed in claim 13 in which said heater sheaths and said sensor containing sheath are embedded in a mass of compacted, electrically non-conductive material within said outer sheath means.

15. An electrical heater as claimed in claim 13 in which the heat sensing means of said sensor containing sheath is disposed in close proximity to a selected one of said groups of heater sheaths and the contained resistance elements.

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