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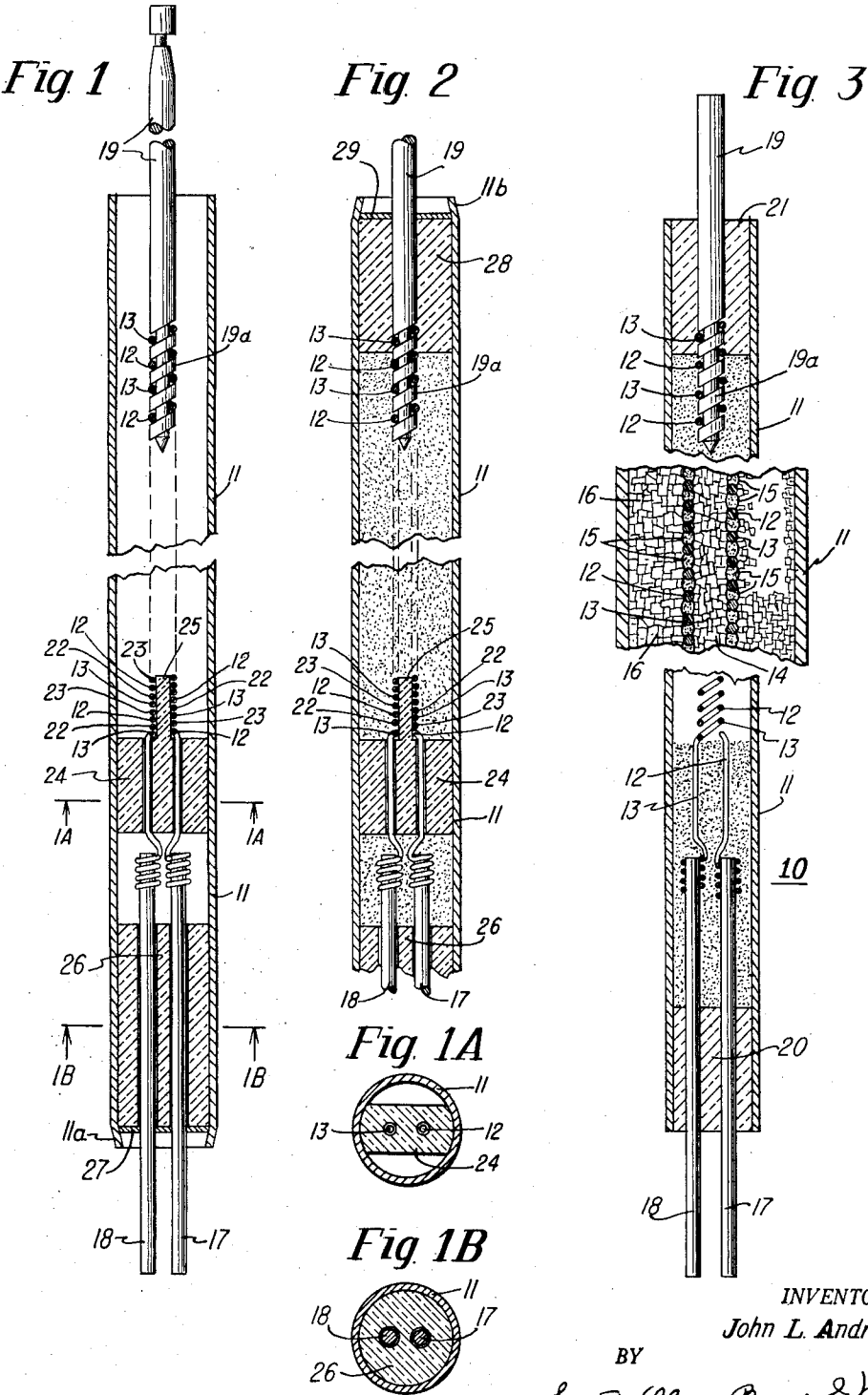
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2,899,664

ELECTRIC HEATING UNITS AND METHODS OF MAKING THE SAME

Filed Feb. 27, 1956

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

Fig. 4

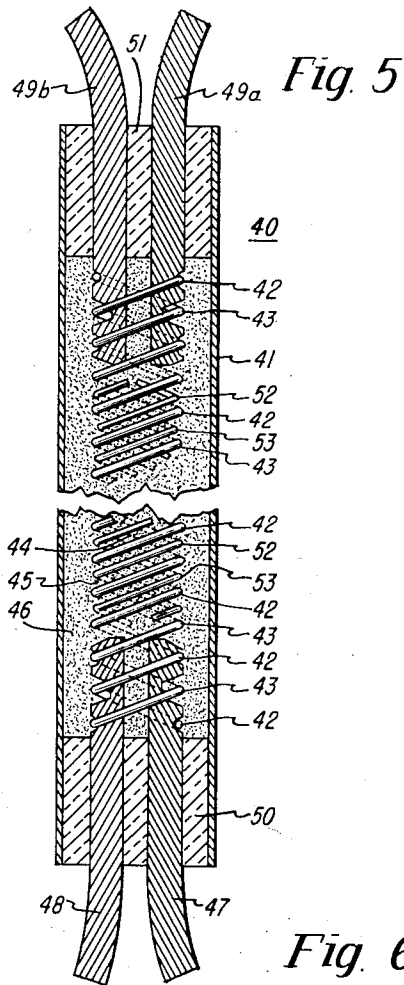
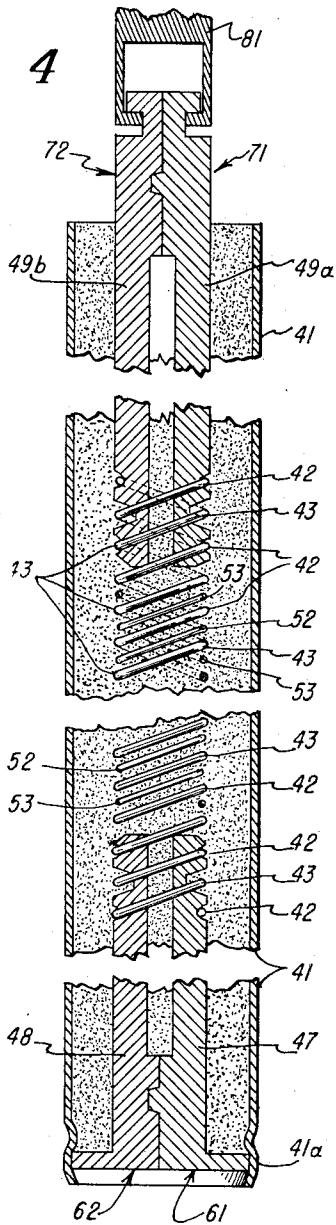
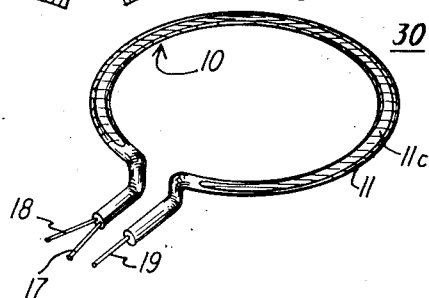


Fig. 5

Fig. 6



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2,899,664

ELECTRIC HEATING UNITS AND METHODS OF MAKING THE SAME

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Application February 27, 1956, Serial No. 567,759

7 Claims. (Cl. 338—240)

The present invention relates to electric heating units of the sheathed resistance conductor type and to methods of making the same.

It is a general object of the invention to provide an electric heating unit of the sheathed resistance conductor type and comprising a plurality of elongated helical resistance conductors arranged in multifilar spaced-apart relation and retained in place in the elongated enclosing metallic sheath and in spaced relation with respect to the sheath by a dense mass of highly compacted refractory material embedding the resistance conductors; wherein the mass of refractory material is of composite structure including a core of crystalline magnesium oxide disposed within the turns of the resistance conductors, an intermediate layer of amorphous magnesium oxide disposed upon the core and between the turns of the resistance conductors, and an outer layer of crystalline magnesium oxide disposed upon the resistance conductors and the intermediate layer and extending into contact with the sheath.

Another object of the invention is to provide a method of making an electric heating unit of the sheathed resistance conductor type and comprising a plurality of elongated helical resistance conductors arranged in multifilar spaced-apart relation and retained in place in the elongated enclosing metal sheath and in spaced relation with respect to the sheath by a dense mass of highly compacted refractory material embedding the resistance conductors; wherein the method involves improved steps that positively insure maintenance of proper spacing of the turns of the resistance conductors incident to compacting of the embedding refractory material; thereby to insure proper spacing of the turns of the resistance conductor with respect to each other and to the sheath in the finished heating unit.

A further object of the invention is to provide an electric heating unit of the character described and including an improved and compact arrangement of the terminals thereof.

A further object of the invention is to provide an improved method of making electric heating units of the sheathed resistance conductor type that is generally applicable thereto without specific limitation as to the number of elongated helical resistance conductors arranged in the elongated enclosing metallic sheath, whereby the turns of the one or more resistance conductors are disposed in proper spaced-apart relation with respect to each other and to the sheath in the finished heating unit.

A still further object of the invention is to provide a method of making an electric heating unit of the sheathed resistance conductor type that involves improved steps wherein an elongated spacing member formed essentially of a metal selected from the group consisting of beryllium, magnesium, aluminum and titanium is first employed to insure maintenance of proper position of the turns of the elongated helical resistance conductor or conductors incident to loading and compacting of re-

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fractory material into the elongated enclosing metallic sheath, and wherein the spacing member is then oxidized to the corresponding metal oxide in order to provide a composite body of refractory material embedding the turns of the resistance conductor or conductors and maintaining proper position thereof and to obtain the additional compacting of the composite mass of refractory material incident to the conversion of the spacing member from the metal mentioned to the corresponding metal oxide.

Further features of the invention pertain to the particular arrangement of the elements of the electric heating unit and of the steps of the method, whereby the above-outlined and additional operating features thereof are attained.

The invention, both as to its organization and method of operation, together with further objects and advantages thereof, will best be understood by reference to the following specification taken in connection with the accompanying drawings, in which:

Figure 1 is an enlarged fragmentary sectional view, of an assembly that is employed in making an electric heating unit of the sheathed resistance conductor type in accordance with the method of the present invention;

Figure 1A is an enlarged sectional view of the assembly taken along the line 1A—1A in Fig. 1;

Figure 1B is another enlarged sectional view of the assembly taken along the line 1B—1B in Fig. 1;

Figure 2 is an enlarged fragmentary sectional view of the assembly of Fig. 1 following certain steps of the method;

Figure 3 is an enlarged fragmentary sectional view, at two different scales, of the finished electric heating unit that has been produced from the assembly of Figs. 1 and 2, the mid-portion of the heating unit of Fig. 3 being at a greatly enlarged scale for the purpose of illustrating diagrammatically the different compositions of the refractory material embedding the resistance conductors in the enclosing sheath;

Figure 4 is an enlarged fragmentary sectional view of a modified form of an assembly that is employed in making an electric heating unit of the type noted in accordance with the method of the present invention;

Figure 5 is an enlarged sectional view of the finished electric heating unit that has been produced from the assembly of Fig. 4; and

Figure 6 is a perspective view of an electric heater, a coil of a hotplate, that has been produced from the finished electric heating unit of Fig. 3.

Referring now to Fig. 3 of the drawings, the electric heating unit 10 there illustrated, and embodying the features of the present invention and made in accordance with the method thereof, fundamentally comprises an elongated tubular metallic sheath 11 that may be formed of a suitable nickel-chromium-iron alloy and having a substantially circular cross-section, and a pair of elongated helical resistance conductors or elements 12 and 13 that may be formed of a suitable nickel-chromium alloy and arranged in bifilar relation and located substantially centrally within the sheath 11 and embedded in a body of heat-conducting and electrical-insulating material of composite structure including a central core portion 14 formed of crystalline magnesium oxide and disposed within the turns of the resistance conductors 12 and 13, an intermediate layer or portion 15 of anhydrous amorphous magnesium oxide and disposed upon the core 14 and between the turns of the resistance conductors 12 and 13, and an outer layer or portion 16 of crystalline magnesium oxide and disposed upon the resistance conductors 12 and 13 and the intermediate layer 15 and extending into contact with the sheath 11. The position and arrangement of the portions 14, 15

and 16 of the composite body of highly compacted refractory material disposed in the sheath 11 and embedding the resistance conductors 12 and 13 retaining the same in place and in proper spaced-apart relation with respect to each other and to the sheath 11, is shown diagrammatically in the enlarged fragmentary mid-portion of Fig. 3.

Also the unit 10 comprises a pair of elongated conductive terminals 17 and 18 arranged in one end of the sheath 11 and respectively electrically connected at the inner ends thereof to the adjacent ends of the resistance conductors 12 and 13, and a single elongated conductive terminal 19 arranged in the other end of the sheath 11 and commonly connected at the inner end thereof to the adjacent ends of the resistance conductors 12 and 13. More particularly, one extremity of the resistance conductor 12 is tightly wound upon the adjacent inner end of the terminal 17 and suitably secured thereto, as by welding, or the like; and one extremity of the resistance conductor 13 is tightly wound upon the adjacent inner end of the terminal 18 and suitably secured thereto, as by welding, or the like. The inner end of the terminal 19 is provided with a compound or double threaded portion, as indicated at 19a, the respective threads of which receive respective adjacent ends or extremities of the resistance conductors 12 and 13. The threaded portion 19a of the terminal 19 may be secured to the adjacent ends of the resistance conductors 12 and 13 by friction alone or by the combination of friction and welding, if required. The outer ends of the terminals 17 and 18 project from the adjacent outer end of the sheath 11 and are sealed in place by an insulating plug 20 formed of glass, or the like; and similarly, the outer end of the terminal 19 projects from the adjacent outer end of the sheath 11 and is sealed in place by an insulating plug 21 formed of glass, or the like.

Accordingly, in the unit 10, the helical resistance conductors 12 and 13 and the terminal 19 are disposed along the longitudinal axis thereof, while the terminals 17 and 18 are disposed in substantially parallel laterally offset position with respect to the longitudinal axis thereof. Of course, it will be understood that suitable electrical connections may be made to the terminals 17, 18 and 19, whereby the resistance conductors 12 and 13 may be utilized individually, in combination in parallel circuit relationship, or in combination in series circuit relationship for selective heating purposes.

In the manufacture of the electric heating unit 10, shown in Fig. 3, first an assembly is produced of the character of that shown in Fig. 1; and specifically the helical resistance conductors 12 and 13 and two elongated spacing members 22 and 23 are first wound in multifilar relation upon an associated mandrel, not shown, the spacing members 22 and 23 being formed essentially of magnesium metal; whereby in the arrangement the sequence of the parts is as follows: a turn of the resistance conductor 12, a turn of the spacing member 22, a turn of the resistance element 13, and a turn of the spacing member 23. Accordingly, between each two adjacent turns of either one of the resistance conductors 12 or 13, there is disposed a turn of the other of the resistance conductors 13 or 12, as well as as a turn of each of the spacing members 22 and 23. After the formation of the composite multifilar helix, one end thereof is assembled upon an insulating plug 24 (see Figs. 1 and 1A), the adjacent extremities of the resistance conductors 12 and 13 being threaded through two longitudinally extending holes provided in the plug 24; and the extreme outer ends of the resistance conductors 12 and 13 are respectively tightly wound upon the adjacent inner ends of the terminals 17 and 18 and suitably welded in place. In producing this sub-assembly, several of the adjacent turns of the resistance conductors 12 and 13 and the spacing members 22 and 23 are tightly wound upon a forwardly projecting pin 25 carried on the inner end

of the plug 24 so as securely to fix the extremities of the two helical resistance conductors 12 and 13. Similarly, the extreme other ends of the resistance conductors 12 and 13 are respectively tightly wound in the respective threads provided in the inner end portion 19a of the terminal 19 and suitably secured in place by welding, or the like.

In these welding operations, if employed, the fabricator is cautioned not to allow the spacing members 22 and 23 to become heated to elevated temperatures, as they are subject to ignition in air, being formed of magnesium metal.

This sub-assembly of the resistance conductors 12 and 13, the spacing members 22 and 23, the terminals 17, 18 and 19 and the plug 24 is arranged substantially centrally within the tubular sheath 11; and the bottom end of the sheath 11 is suitably closed by an insulating plug 26 provided with two holes therethrough respectively surrounding the intermediate portions of the terminals 17 and 18 (see Fig. 1B) and by a metal backing washer 27 arranged in the bottom end of the sheath 11 in surrounding relation with the intermediate portions of the terminals 17 and 18 and exteriorly of the plug 26. Then the extreme bottom end of the sheath 11 is bent over, as indicated at 11a, in order to retain the washer 27 in place.

At this time, the assembly is transferred to a loading machine of the character of that disclosed in U.S. Patent No. 2,316,659, granted on April 13, 1943, to John L. Andrews; the terminal 19 being arranged at the top of the loading machine and being held in place by a hook, not shown; whereby the resistance conductors 12 and 13 and the spacing members 22 and 23 are in a position depending from the terminal 19 and disposed substantially centrally within the upstanding tubular sheath 11. The loading machine is then operated in a conventional manner, whereby a charge of finely divided crystalline magnesium oxide is introduced into the upper end of the sheath 11 adjacent to the terminal 19 and into embedding relation with respect to the resistance conductors 12 and 13, the magnesium metal spacing members 22 and 23 and the inner ends of the terminals 17, 18 and 19. In passing, it is noted that the plug 24, as shown in Fig. 1A, does not fill completely the tubular sheath 11 so that the charge of finely divided crystalline magnesium oxide introduced into the sheath 11 may fill the space between the plugs 24 and 26 and embed the extreme inner ends of the terminals 17 and 18. On the other hand, the plug 26, as shown in Fig. 1B, substantially completely fills the tubular sheath 11, thereby serving as a stopper preventing the finely divided refractory material from falling out of the lower end of the tubular sheath 11. When the charge of refractory material is introduced into the sheath 11, it is tamped or hammered into place to provide a firm, but porous, packing filling the central core surrounded by the resistance conductors 12 and 13 and by the spacing members 22 and 23, as well as the space surrounding the parts 12, 13, 22, 23, 17, 18 and 19 and enclosed by the sheath 11, as indicated in Fig. 2.

After filling of the sheath 11, the assembly is removed from the loading machine mentioned and the upper end of the sheath 11, as shown in Fig. 2, is closed by an insulating plug 28 and an associated metal backing washer 29, the extreme upper end of the sheath 11 being bent over to retain the backing washer 29 in place, as indicated at 11b. Also the extreme upper end of the terminal 19 that cooperates with the hook provided in the loading machine is severed. At this time, the assembly of Fig. 2 is produced; and in passing, it is mentioned that the plugs 24, 26 and 28 may be of the frangible insulating type consisting essentially of a chalk-like material or porcelain character. However, it is noted that while the plugs 24, 26 and 28 retain the charge of refractory material in place within the sheath 11, they are not sealed in air-tight relation to the sheath 11, and they are not

sealed in air-tight relation to the intermediate portions of the adjacent terminals 17, 18 and 19.

At this time, the assembly is transferred to a rolling machine of the character of that disclosed in U.S. Patent No. 2,677,172, granted on May 4, 1954, to Sterling A. Oakley; and the rolling machine is operated in order to subject the assembly to a preliminary compacting step, the assembly being moved upwardly, while supported in an upright position, through the several rolling passes thereof. Specifically, in the preliminary rolling operation, the diameter of the sheath 11 is modestly reduced so as modestly to reduce the cross-sectional area of the charge of refractory material and so as to crush the frangible plugs 24, 26 and 28 in order to obtain the corresponding modest compacting of the refractory material arranged in the sheath 11 and supporting the elements 12, 13, 22, 23, 17, 18 and 19 in the assembled positions thereof. At this time, following the preliminary rolling step, the charge of crystalline magnesium oxide, as well as the refractory material resulting from the crushing of the frangible plugs 24, 26 and 28 is still porous, as explained more fully below.

Following the preliminary rolling step, the assembly, having substantially the appearance as illustrated in Fig. 2, is transferred to an autoclave of conventional construction including a heating chamber, an associated electric heater, a connecting vacuum pump, a connecting oxygen tank provided with a pressure regulator, pressure gauges and suitable valves and fittings, all of a known character. In the autoclave, the assembly is subjected to heat treatment in order to effect oxidation, in any suitable manner, of the spacing members 22 and 23, so that they are converted from magnesium metal to anhydrous amorphous magnesium oxide; and preferably, the steps that are carried out in the autoclave mentioned are in accordance with the process disclosed in the copending application of Emmett W. Barnes, Ser. No. 567,849, filed February 27, 1956.

In accordance with the Barnes process, the heating chamber of the autoclave is closed after the assembly is loaded thereinto; and actually the heating chamber is arranged to receive a substantial group or number of the assemblies, as a matter of production facility. After closing and sealing of the heating chamber, it is evacuated and the vacuum is held for about 15 minutes, so as to remove air from the porous packing of refractory material enclosed in the sheath 11. Thereafter, gaseous oxygen is introduced into the heating chamber under gauge pressure of about 70 p.s.i., and the assembly is soaked therein for about 15 minutes. Again the heating chamber is evacuated and the vacuum is held for about 15 minutes, so as to remove residual air from the porous packing of refractory material enclosed in the sheath 11. Thereafter, gaseous oxygen is again introduced into the heating chamber under gauge pressure of about 70 p.s.i.; and this pressure is maintained therein in order again to permeate the packing of refractory material and to contact the magnesium metal spacing members 22 and 23. The temperature of the heating chamber is then elevated to a reaction temperature disposed below the ignition temperature of magnesium metal at the gauge pressure of about 70 p.s. i., which elevated reaction temperature is maintained for a sufficient time interval completely to react the magnesium metal spacing members 22 and 23, so as completely to convert the same to anhydrous amorphous magnesium oxide; whereby the mass of amorphous magnesium oxide comprising the layer 15 is produced in the assembly, as indicated in Fig. 3.

It has been discovered that under the reaction conditions specified, the ignition temperature of magnesium metal is about 1085° F., whereby the reaction temperature is maintained in the heating chamber at about 1075° F., this reaction temperature being safely below the ignition temperature of magnesium metal, yet sufficiently close thereto to insure a high rate of reaction. It is esti-

mated that in the manufacture of the heating unit 10, the required time interval of the reaction is about 8 hours; however, the assembly is retained in the autoclave under the reaction conditions set forth for a time interval of about 16 hours, so as positively to insure the complete conversion of the spacing members 22 and 23 from magnesium metal to magnesium oxide. Specifically, this time interval is not critical, provided it is sufficiently long to insure the complete reaction of all of the magnesium metal and the complete conversion thereof to amorphous magnesium oxide; i.e., the maintenance of the reaction conditions in the heating chamber of the autoclave for some time interval following the complete conversion of the magnesium metal to amorphous magnesium oxide is in nowise deleterious, since the reaction is automatically terminated when the conversion is completed.

After the complete reaction of the magnesium metal spacing members 22 and 23 has been achieved in the autoclave, the heating chamber thereof is opened to the atmosphere and allowed to cool; whereupon the assembly is removed from the heating chamber and again transferred to the rolling machine; whereupon it is subjected to a final compacting step, similar to the preliminary compacting step previously described, but substantially more severe. In the final rolling operation, the diameter of the sheath 11 is substantially reduced so as substantially to reduce the cross-sectional area of the composite body of refractory material including the layer 15 of amorphous magnesium oxide, the surrounded core 14 of crystalline magnesium oxide and the surrounding layer 16 of crystalline magnesium oxide, so as to produce a highly compacted dense composite body of refractory material embedding the helical resistance conductors 12 and 13 and retaining the same in spaced-apart relation with respect to each other and with respect to the sheath 11. The dense mass of compacted refractory material also positions and retains in place the terminals 17, 18 and 19.

After the final rolling operation, the assembly is removed from the rolling machine and the extreme outer ends of the sheath 11 are severed so as to remove the backing washers 27 and 29, as well as the bent-over ends 11A and 11B of the tubular sheath 11. Finally, the portions of the compacted refractory material disposed in the extreme outer ends of the sheath 11 and respectively surrounding the terminals 17, 18 and 19 are removed to provide the cavities into which the glass plugs or seals 20 and 21 are ultimately cast so as firmly to retain the terminals 17, 18 and 19 in place and so as to seal the opposite ends of the tubular sheath 11, as shown in Fig. 3.

After manufacture of the heating unit 10, it is ordinarily subjected to the usual electrical tests in order to determine the insulation resistance, proof voltage, heat distribution, and other matters affecting the performance and life of the unit.

As a constructional example of the manufacture of the heating unit 10, the tubular sheath 11 may have an initial diameter of 0.312"; and in the preliminary rolling step, the diameter thereof may be reduced to 0.299"; and thereafter in the final rolling step, the diameter thereof may be reduced to 0.270". In the heating unit 10: the resistance conductor 12 may be formed of #30A (B. & S.) gauge wire having a diameter of about 0.0110"; the resistance conductor 13 may be formed of #31A (B. & S.) gauge wire having a diameter of about 0.0089"; and each of the spacing members 22 and 23 may be formed of magnesium wire having a diameter of about 0.0140". In the assembly of Fig. 1, the spacing between each resistance conductor 12 and 13 and the associated spacing member 22 and 23 may be about 0.010", thereby accommodating the passage of the finely divided crystalline magnesium oxide therethrough into the interior of the composite multifilar helix thus produced incident to operation of the loading machine. Also in the assembly

of Fig. 1, the outside diameter of the turns of the composite multifilar helix may be about 0.110".

Of course, the number of turns per inch longitudinally of the composite multifilar helix of each of the elements 12, 13, 22 and 23 is dependent fundamentally upon the gauges of the resistance conductors 12 and 13 that, in turn, is dependent upon the desired wattage rating of the finished heating unit 10. However, as a practical matter, it has been discovered that from 10 to 21 turns per inch longitudinally of the composite multifilar helix is feasible, when both of the resistance conductors 12 and 13 are formed respectively of relatively coarse and relatively fine resistance wire.

In a modification of the method of making the heating unit 10, the assembly is subjected to heat treatment in the autoclave in the manner described only throughout a relatively short time interval so as to effect the conversion of only the outer skins of the magnesium spacing member 22 and 23 into amorphous magnesium oxide leaving the interior cores thereof as the original magnesium metal. For example, the outer skins of the members 22 and 23 may be converted into magnesium oxide, so that the conversion of the members 22 and 23 is about 10% complete, by treatment in the autoclave throughout a time interval of about 2 hours.

After the manufacture of the heating unit 10, it is incorporated in an appliance, or the like, such, for example, as an electric hotplate, as illustrated in Fig. 6. Specifically, a heating element 30 of a hotplate is illustrated in Fig. 6; and the heating element 30 is formed from the heating unit 10 by appropriate bending thereof into the required configuration followed by flattening of the upper surface of the sheath 11, as indicated at 11c. This flattening of the upper surface or top of the sheath 11, as indicated at 11c, of the heating element 30, not only accommodates the ready support of a cooking vessel to be heated, but it also effects further tightening or compacting of the mass of refractory material enclosed in the sheath 11, as well as the elimination of any cracks or fissures in the refractory material that might be produced therein incident to the bending of the heating unit 10 into the desired configuration of the heating element 30.

Referring now to Fig. 5 of the drawings, the electric heating unit 40 there illustrated and made in accordance with the method of the present invention is fundamentally of the same construction as the heating unit 10 described above, and is made fundamentally in the manner previously explained; whereby the heating unit 40 comprises the corresponding elements 41, 42, 43, 47 and 48, as well as the composite body of refractory material including the portions 44, 45 and 46. It will be recalled: the core portion 44 of refractory material is formed of crystalline magnesium oxide; the intermediate portion 45 of the refractory material is formed of anhydrous amorphous magnesium oxide; and the outer portion 46 of the refractory material is formed of crystalline magnesium oxide.

However, in the embodiment of the heating unit 40 the terminals at the opposite ends of the sheath 41 are distinct and separate so that one end thereof comprises the terminals 47 and 48 and the other end thereof comprises the terminals 49a and 49b. Specifically: the helical resistance conductor 42 extends between the terminals 47 and 49a, the opposite ends thereof being respectively electrically connected thereto; while the helical resistance conductor 43 extends between the terminals 48 and 49b, the opposite end thereof being respectively electrically connected thereto; and again the elongated helical resistance conductors 42 and 43 are wound in bifilar relation. Accordingly, it will be appreciated that the electric circuit of the resistance conductor 42 between the terminals 47 and 49a is entirely independent of the electric circuit of the resistance conductor 43 between the terminals 48 and 49b. Specifically, at least two turns of the resistance conductor 42 at one end thereof are welded

to two longitudinally spaced-apart and outwardly directed ridges provided on the inner end of the terminal 47 and separated by an intervening notch in which one turn of the resistance conductor 43 is disposed in spaced-apart relation with respect to the inner end of the terminal 47. Similarly, at least two turns of the resistance conductor 43 at one end thereof are welded to two longitudinally spaced-apart and outwardly directed ridges provided on the inner end of the terminal 48 and separated by an intervening notch in which one turn of the resistance conductor 42 is disposed in spaced-apart relation with respect to the inner end of the terminal 48. Accordingly, it will be understood that while the adjacent inner ends of the terminals 47 and 48 extend within the adjacent ends of the bifilar wound resistance conductors 42 and 43, the terminal 47 is electrically connected only to the resistance conductor 42 and the terminal 48 is electrically connected only to the resistance conductor 43.

The arrangement and relationship of the resistance conductors 42 and 43 and the respective terminals 49a and 49b at the other end of the heating unit 40 are the same as those described above in conjunction with the one end of the heating unit 40 and are not reiterated in the interest of brevity; whereby, it will be understood that the terminal arrangement at the opposite ends of the heating unit 40 are identical. Moreover, in this case the glass insulating plugs 50 and 51 respectively provided in the opposite ends of the sheath 41 respectively seal the opposite ends thereof and respectively embed the terminal pairs 47-48 and 49a-49b.

In the production of the heating unit 40 of Fig. 5, there is first produced the assembly illustrated in Fig. 4; and initially there is provided a lower subassembly including a pair of complementary fixtures 61 and 62 and an upper sub-assembly including a pair of complementary fixtures 71 and 72. The fixtures 61 and 62 are detachably secured together and provide, when assembled, a composite head or plug and are respectively provided with the two longitudinally extending and laterally spaced-apart shanks that are ultimately fashioned into the respective terminals 47 and 48. Similarly, the fixtures 71 and 72 are detachably secured together and provide, when assembled, a composite head and respectively provided with the two longitudinally extending and laterally spaced-apart shanks that ultimately are fashioned into the respective terminals 49a and 49b. Accordingly, the lower sub-assembly of the two fixtures 61 and 62 is substantially U-shaped including the junction or head and the two longitudinally extending shanks 47 and 48; and likewise, the upper sub-assembly of the two fixtures 71 and 72 is substantially U-shaped including the junction or head and the two longitudinally extending shanks 49a and 49b.

In producing the assembly of Fig. 4, the composite multifilar helix is provided that includes the two elongated helical resistance conductors 42 and 43 and the two elongated helical spacing members 52 and 53 wound in multifilar relation, as previously explained; and the opposite ends of the composite helix are respectively assembled with respect to the lower and upper sub-assemblies. Specifically, the lower ends of the resistance conductors 42 and 43 are suitably secured by welding, or the like, to the respective shanks 47 and 48 of the lower sub-assembly; and likewise, the upper end of the resistance conductors 42 and 43 are suitably secured by welding, or the like, to the respective shanks 49a and 49b of the upper sub-assembly. Thereafter, this sub-assembly is arranged within the tubular sheath 41; and the extreme lower end of the sheath 41 is deformed into engagement with the head provided on the lower sub-assembly, as indicated at 41a, so as to close the lower end of the sheath 41.

After this portion of the assembly of Fig. 4 is thus produced, it is transferred to the loading machine; whereby by the head of the upper sub-assembly cooperates with

the hook (indicated at 81) of the loading machine, so as to retain the composite multifilar helix in depending position from the upper sub-assembly and substantially centrally within the tubular sheath 41. The loading machine is operated in order that the finely divided crystalline magnesium oxide is charged into the tubular sheath 41 and in embedding relation with respect to the elements 42, 43, 52 and 53 of the composite multifilar helix, as well as to the shanks 47 and 48 of the lower sub-assembly and the shanks 49a and 49b of the upper sub-assembly, thereby to produce the assembly as shown in Fig. 4. Then the assembly is removed from the loading machine and the upper end of the sheath 41 is closed with a suitable backing washer, not shown, so as to retain the charge of crystalline magnesium oxide in place, embedding the elements arranged within the tubular sheath 41.

Then the assembly is subjected to the preliminary rolling step, as previously described; and thereafter the assembly is subjected to heat-treatment in the autoclave, in the manner previously explained. In the autoclave, the spacing members 52 and 53 formed essentially of magnesium metal are converted into anhydrous amorphous magnesium oxide; whereby the three portions 44, 45 and 46 of the composite mass of refractory material provided in the sheath 41 are produced, in the manner previously explained. Still subsequently, the assembly is subjected to the final rolling step in the rolling machine; thereafter, the lower end of the sheath 41 and the lower sub-assembly are cut-off to produce the two separate and distinct terminals 47 and 48; and likewise, the upper end of the sheath 41 and the upper sub-assemblies are cut off to produce the two separate and distinct terminals 49a and 49b. Ultimately the terminals 47—48 and the terminals 49a—49b are respectively bent outwardly with respect to each other, and then the glass plugs 50 and 51 are cast into the opposite ends of the tubular sheath 41 so as to produce the finished heating unit, as illustrated in Fig. 5.

In a modification of the method of making the heating unit 40, the assembly is subjected to heat treatment in the autoclave in the manner described only throughout a relatively short time interval so as to effect only the conversion of the outer skins of the magnesium helices 52 and 53 into amorphous magnesium oxide, leaving the interior cores thereof as the original magnesium metal. For example, the outer skins of the helices 52 and 53 may be converted into magnesium oxide, so that the conversion of the helices 52 and 53 is about 10% complete, by treatment in the autoclave throughout a time interval of about 2 hours.

Of course, the finished heating unit 40 may be subsequently worked in the manner of the finished heating unit 10, described above, in order to produce a heating element therefrom that is substantially identical to the heating element 30 of Fig. 6, except that the electrical circuits for the resistance conductors 42 and 43 are distinct in that each of the resistance conductors is provided with its individual pair of terminals at the opposite end of the tubular sheath 41.

The arrangement of the terminal structure of the electric heating unit 40, and the method of making the same, are claimed in the copending divisional application of John L. Andrews, Serial No. 649,386, filed March 29, 1957, now Patent No. 2,858,401, granted October 28, 1958.

In the manufacture of either of the heating units 10 or 40, it will be understood that during loading and tamping in place of the charge of finely divided crystalline magnesium oxide into the sheath in the loading machine, that the pair of spacing members formed of magnesium metal serve the function of retaining in place the pair of resistance conductors; which arrangement is very advantageous in view of the close longitudinal spacing between adjacent turns of the resistance conductors. Thereafter when the spacing members formed of magnesium metal are oxidized in the autoclave into anhydrous amorphous

magnesium oxide, there is a corresponding expansion of the volume occupied thereby within the enclosing sheath, since there is an expansion of about 200% when a given mass of magnesium metal is converted into a corresponding mass of anhydrous amorphous magnesium oxide by oxidation. This action of course produces further compacting of the resulting mass of refractory material in the sheath of the heating unit further eliminating voids therein and further contributing toward the production of a dense mass of refractory material in the finished heating unit embedding the resistance conductors and retaining the same in place. This feature is very advantageous, as it will be understood that the composite mass of refractory material mentioned not only serves the mechanical functions described with respect to holding the resistance conductors in place in insulated condition with respect to the surrounding sheath, but it also serves the function of transmitting the heat produced in the resistance conductors to the sheath for the useful heating purpose. It is emphasized that the last-mentioned function is very important as it not only contributes to efficiency of the finished electric heating unit, but it also prevents excessive temperatures of the resistance conductors, thereby materially contributing to desirable long life of the heating unit.

Again referring to Fig. 3, it is pointed out that the peculiar arrangement of the layer 15 of amorphous magnesium oxide between the turns of the resistance conductors 12 and 13 are in an intimate position with respect to the central core 14 of crystalline magnesium oxide and the outer layer 16 of crystalline magnesium oxide is most advantageous due to the circumstances that amorphous magnesium oxide has both a higher coefficient of electrical resistance and a lower coefficient of heat conductivity than does crystalline magnesium oxide. Thus: the amorphous magnesium oxide of the layer 15 is a better electrical insulator between adjacent turns of the resistance conductors 12 and 13 than are the layers 14 and 16 of crystalline magnesium oxide; and moreover, the amorphous magnesium oxide of the layer 15 is a poorer heat conductor between adjacent turns of the resistance conductors 12 and 13 than are the layers 14 and 16 of crystalline magnesium oxide. Accordingly, the layer 15 of amorphous magnesium oxide is substantially ideally suited to utilization between the turns of the resistance conductors 12 and 13, since it has both a high electrical insulating characteristic and a low heat conducting characteristic, thereby minimizing undesirable electrical and heating effects between the resistance conductors 12 and 13, without in any way impairing the efficiency of the heating unit 10.

Of course, the advantages of the construction of the heating unit 10, described above, are present in the heating unit 40, since the layer 45 of amorphous magnesium oxide is arranged between the turns of the resistance conductors 42 and 43 in this construction.

In conjunction with the operation of the autoclave, the processor is cautioned that the reaction temperature maintained in the heating chamber thereof must not be permitted to rise to the ignition temperature of magnesium metal, since it will be apparent that the ignition of the magnesium metal will bring about the production of an exceedingly high temperature, with the consequent melting of the adjacent resistance conductors, or even the enclosing sheath of the heating unit undergoing the heat treatment. Fortunately, the ignition temperature of magnesium metal in gaseous oxygen at a gauge pressure of about 70 p.s.i. is well-defined at 1085° F., whereby the reaction temperature of 1075° F. is entirely safe for this step. In this connection, it is noted that the ignition temperature of the magnesium metal is related to the pressure of the atmosphere of gaseous oxygen, the ignition temperature increasing with increasing pressures of the gaseous oxygen atmosphere. Thus, it will be appreciated that the reaction temperature-gauge pressure

relationship mentioned is capable of appropriate variation dependent upon the factors noted; however, from a practical standpoint, the relatively low gauge pressure of about 70 p.s.i. and the readily controllable reaction temperature of about 1075° F. are recommended for commercial production of the heating units in accordance with the present method.

It is pointed out that while each of the heating units 10 and 40 comprises two individual elongated helical resistance conductors, the present method is in no way limited to these specific examples, as the advantages thereof may be realized in a heating unit comprising only a single elongated helical resistance conductor; although, of course, the important advantages of the method are utilized to the fullest extent in the production of heating units of the multiple resistance conductor type. Thus it will be appreciated that in accordance with the present method, the heating unit may comprise 1, 2, 3, etc., elongated helical resistance conductors arranged in the elongated enclosing metallic sheath; and that in the corresponding cases the required magnesium metal spacing member or members are provided and wound in multifilar relation with the resistance conductor or conductors in the production of the assembly that is ultimately employed in making the finished heating unit.

In the foregoing explanation of the present method, the members 22 and 23 of the assembly of Fig. 1 and the members 52 and 53 of the assembly of Fig. 4 were described as being formed essentially of magnesium metal; however, a modification is contemplated, wherein these members are formed essentially of beryllium, magnesium, aluminum or titanium, or alloys thereof, as it will be understood that the elements named comprise a well-defined group of metals that may be readily converted from the metallic form into the corresponding metal oxide by oxidation with gaseous oxygen under gauge pressure and at an elevated temperature in the autoclave in a manner substantially identical to that described, and wherein each of the corresponding metal oxides constitutes a refractory material having good electrical-insulating and good heat-conducting properties. In each case, the operating temperature of the heating chamber of the autoclave is established somewhat below the ignition temperature of the corresponding metal or alloy, so as to prevent ignition of the metal members in the atmosphere of oxygen gas under gauge pressure at the elevated temperature.

In view of the foregoing, it is apparent that there has been provided both an electric heating unit of improved construction and arrangement, as well as an improved method of making the same, that may be readily carried out upon a mass production basis for commercial purposes.

While there has been described what is at present considered to be the preferred embodiment of the invention, it will be understood that various modifications may be made therein, and it is intended to cover in the appended claims all such modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. An electric heating unit comprising an elongated helical resistance conductor, an elongated tubular metallic sheath enclosing said resistance conductor and spaced therefrom, and a dense mass of compacted refractory material arranged in said sheath and embedding said resistance conductor and retaining the same in place in spaced relation with respect to said sheath; wherein said mass of refractory material includes a core of crystalline magnesium oxide disposed within the turns of said resistance conductor, an intermediate layer of amorphous magnesium oxide disposed upon said core and between the turns of said resistance conductor, and an outer layer of crystalline magnesium oxide disposed upon said resistance conductor and said intermediate layer and extending into contact with said sheath; and wherein said

amorphous magnesium oxide has both a higher coefficient of electrical resistance and a lower coefficient of heat conductivity than said crystalline magnesium oxide.

2. An electric heating unit comprising a pair of elongated helical resistance conductors arranged in bifilar relation with a turn of one of said resistance conductors arranged between each two adjacent turns of the other of said resistance conductors and with the turns of said resistance conductors in spaced relation, an elongated tubular metallic sheath enclosing said pair of resistance conductors and spaced therefrom, and a dense mass of compacted refractory material arranged in said sheath and embedding said pair of resistance conductors and retaining the same in place in spaced relation mutually with respect to each other and with respect to said sheath; wherein said mass of refractory material includes a core of crystalline magnesium oxide disposed within the turns of said pair of resistance conductors, an intermediate layer of amorphous magnesium oxide disposed upon said core and between the turns of said pair of resistance conductors, and an outer layer of crystalline magnesium oxide disposed upon said pair of resistance conductors and said intermediate layer and extending into contact with said sheath; and wherein said amorphous magnesium oxide has both a higher coefficient of electrical resistance and a lower coefficient of heat conductivity than said crystalline magnesium oxide.

3. The method of making an electric heating unit of the sheathed resistance conductor type, which comprises: providing an elongated resistance conductor, providing an elongated spacing member formed essentially of a metal selected from the group consisting of beryllium, magnesium, aluminum and titanium, winding said resistance conductor and said spacing member into helical form in bifilar relation with a turn of said spacing member arranged between each two adjacent turns of said resistance conductor, providing an elongated tubular metallic sheath, enclosing said winding of said resistance conductor and said spacing member in said sheath and in spaced relation therewith, loading a porous packing of finely divided electrical-insulating and heat-conducting refractory material into said sheath in embedding relation with both said resistance conductor and said spacing member and so as to retain the same in place in spaced relation with respect to said sheath, working the assembly of said elements named to reduce the cross-sectional area of said sheath in order to compact somewhat said porous packing of refractory material, and then subjecting said assembly to heat treatment in an oxidizing atmosphere permeating said compacted porous packing of refractory material.

4. The method of making an electric heating unit of the sheathed resistance conductor type, which comprises: providing an elongated resistance conductor, providing an elongated spacing member formed essentially of a metal selected from the group consisting of beryllium, magnesium, aluminum and titanium, winding said resistance conductor and said spacing member into helical form in bifilar relation with a turn of said spacing member arranged between each two adjacent turns of said resistance conductor, providing an elongated tubular metallic sheath, enclosing said winding of said resistance conductor and said spacing member in said sheath and in spaced relation therewith, loading a porous packing of finely divided electrical-insulating and heat-conducting refractory material into said sheath in embedding relation with both said resistance conductor and said spacing member and so as to retain the same in place in spaced relation with respect to said sheath, subjecting the assembly of said elements named to heat treatment in an oxidizing atmosphere permeating said porous packing of refractory material for a sufficient time interval to

convert said spacing member into a charge of the corresponding metal oxide while it is thus embedded in said porous packing of refractory material, and then working said assembly to reduce the cross-sectional area of said sheath in order to compact both said packing of refractory material and said charge of metal oxide into a composite dense mass embedding said resistance conductor and filling the space between said resistance conductor and said sheath.

5. The method of making an electric heating unit of the sheathed resistance conductor type, which comprises: providing an elongated helical resistance conductor, providing an elongated spacing member formed essentially of a metal selected from the group consisting of beryllium, magnesium, aluminum and titanium, winding said resistance conductor and said spacing member into helical form in bifilar relation with a turn of said spacing member arranged between each two adjacent turns of said resistance conductor, providing an elongated tubular metallic sheath, enclosing said winding of said resistance conductor and said spacing member in said sheath and in spaced relation therewith, loading a porous packing of finely divided electrical-insulating and heat-conducting refractory material into said sheath in embedding relation with both said resistance conductor and said spacing member and so as to retain the same in place in spaced relation with respect to said sheath, working the assembly of said elements named to reduce somewhat the cross-sectional area of said sheath in order to compact somewhat said porous packing of refractory material, heat treating said assembly in an oxidizing atmosphere permeating said compacted porous packing of refractory material for a sufficient time interval to convert said spacing member into a charge of the corresponding metal oxide while it is thus embedded in said compacted porous packing of refractory material, and then working said assembly to reduce substantially the cross-sectional area of said sheath in order to compact substantially both said packing of refractory material and said charge of metal oxide into a composite dense mass embedding said resistance conductor and filling the space between said resistance conductor and said sheath.

6. The method of making an electric heating unit of the sheathed resistance conductor type, which comprises: providing a pair of elongated resistance conductors, providing a pair of elongated spacing members each formed essentially of a metal selected from the group consisting of beryllium, magnesium, aluminum and titanium, winding said resistance conductors and said spacing members into helical form in multifilar relation with a turn sequence of one of said resistance conductors and then one of said spacing members and then the other of said resistance conductors and then the other of said spacing members, providing an elongated tubular metallic sheath, enclosing said winding of said pair of resistance conductors and said pair of spacing members in said sheath and in spaced relation therewith, loading a porous packing of finely divided electrical-insulating and heat-conducting refractory material into said sheath in embedding relation with both said pair of resistance conductors and said pair of spacing members and so as to retain the same in place in spaced relation with respect to said sheath, and subjecting the assembly of said

elements named to heat treatment in an oxidizing atmosphere permeating said porous packing of refractory material for a sufficient time interval to convert said pair of spacing members into a charge of the corresponding metal oxide while they are thus embedded in said porous packing of refractory material.

7. The method of making an electric heating unit of the sheathed resistance conductor type, which comprises: providing an elongated resistance conductor, providing an elongated spacing member formed essentially of magnesium metal, winding said resistance conductor and said spacing member into helical form in bifilar relation with a turn of said spacing member arranged between each two adjacent turns of said resistance conductor, providing an elongated tubular metallic sheath, enclosing said winding of said resistance conductor and said spacing member in said sheath and in spaced relation therewith, loading a porous packing of finely divided crystalline magnesium oxide into said sheath in embedding relation with both said resistance conductor and said spacing member and so as to retain the same in place in spaced relation with respect to said sheath, and then subjecting the assembly of said elements named to heat treatment in an oxidizing atmosphere permeating said porous packing of crystalline magnesium oxide for a sufficient time interval to convert said spacing member into a charge of amorphous magnesium oxide while it is thus embedded in said porous packing of said crystalline magnesium oxide; whereby a composite body of refractory material is produced that includes an inner core of crystalline magnesium oxide and an intermediate layer of amorphous magnesium oxide disposed between the turns of said resistance conductor and an outer layer of crystalline magnesium oxide; and whereby said resistance conductor and said intermediate layer are retained in place between said core and said outer layer; and wherein said amorphous magnesium oxide has both a higher coefficient of electrical resistance and a lower coefficient of heat conductivity than said crystalline magnesium oxide.

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