

Aug. 14, 1928.

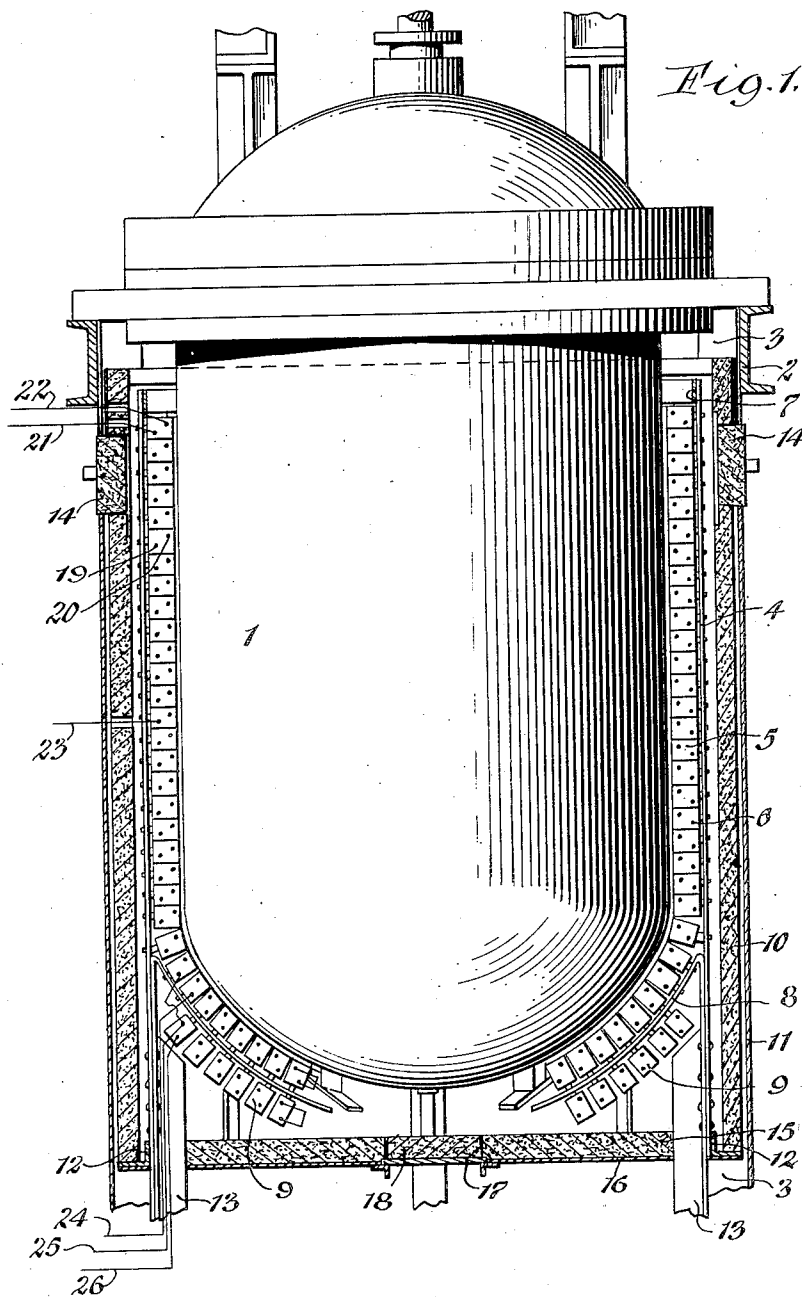
1,680,595

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CURRENT INDUCTION

Filed Oct. 26, 1925

4 Sheets-Sheet 1



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*Fig. 2.*

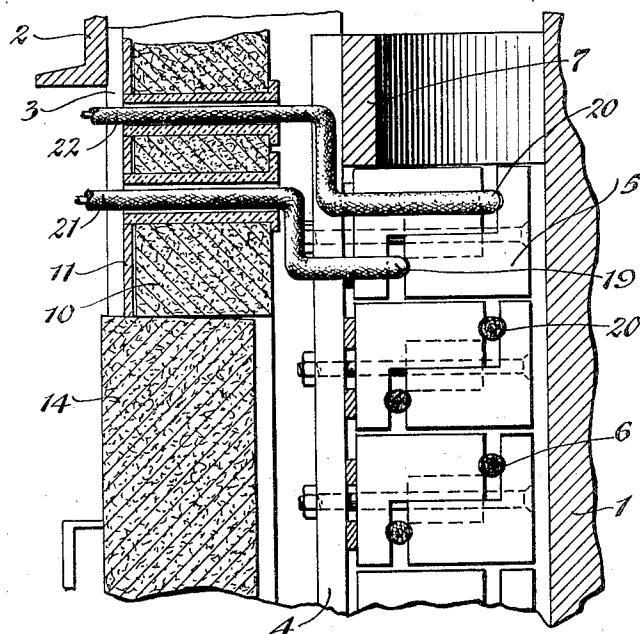
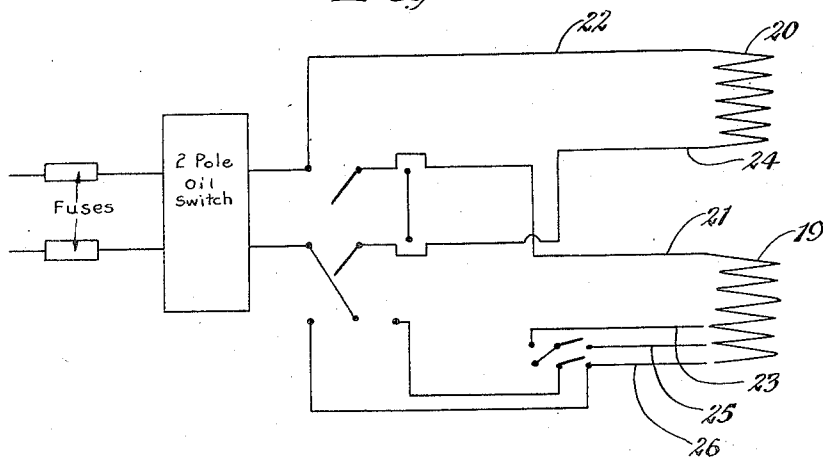


*Fig. 3.*



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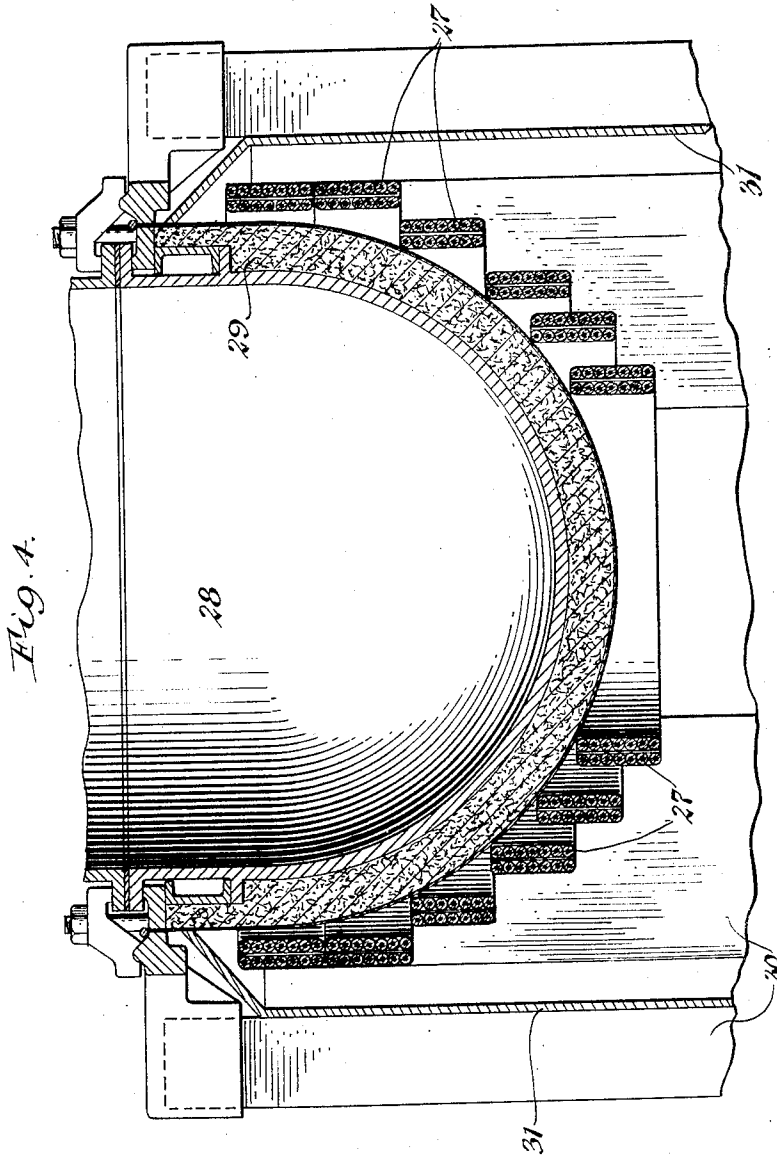
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4 Sheets-Sheet 3



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Fig. 5.

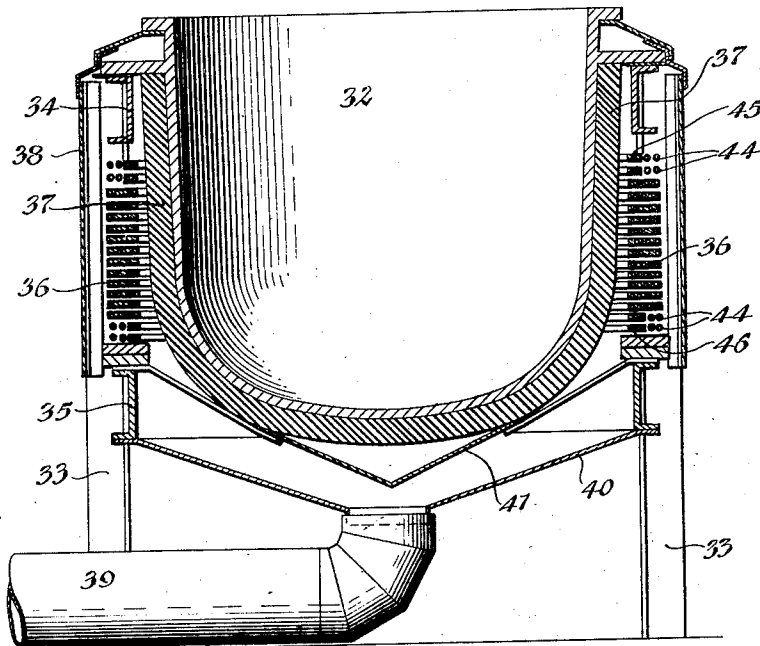
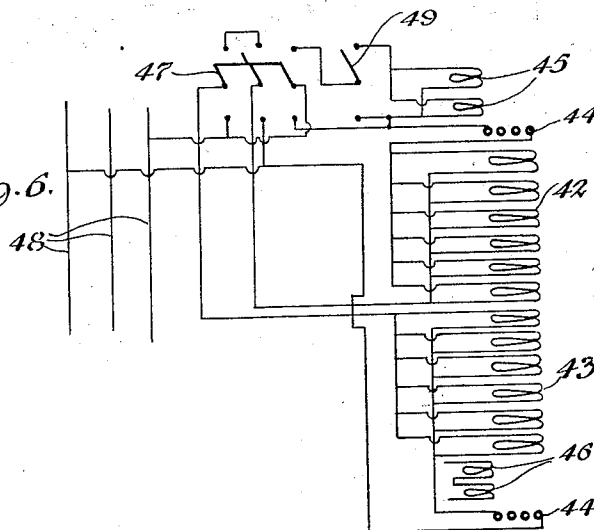


Fig. 6.



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## UNITED STATES PATENT OFFICE.

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## CURRENT INDUCTION.

Application filed October 26, 1925. Serial No. 64,806.

This invention relates to the induction of currents and, in its specific application, to heating by induced currents.

Induced currents in a circuit vary with the number of lines of magnetic flux permeating the circuit; but the number of lines generated is dependent upon the mode of applying the current which causes the magnetic field. The usual arrangement of conductive elements in the form of a solenoid results in a field of varying intensity with more lines of flux within the middle portion than at its ends. Consequently the secondary electromotive forces vary, and the resulting induced currents are modified accordingly.

In addition, I have observed in connection with a solenoid, that the induction of currents is affected by its conformation, or shape, and by the arrangement of the conductive elements constituting the solenoid, that is, whether they are connected in series or in parallel or in combination of series and parallel. These effects may be attributed to leakages of flux lines being accentuated or increased by the change in shape, and to the variations in counter electromotive forces attendant upon the changes in the number of flux lines which are associated with the conductive elements.

The variations of intensity in the magnetic field are of material importance in the application of induced currents for heating purposes, and the use of induced currents for heating a body, such as a vessel, is accordingly made the basis for a disclosure of the invention. It is to be understood, however, that the invention contemplates a wider field, including transformers and related structures, wherein secondary currents are induced for purposes other than heating.

Inductional heating of vessels, such as kettles, autoclaves and pots used in chemical processes, imposes requirements upon the conformation of the solenoid, on account of the variations in shape of the vessels, and the necessity for heat distribution and temperature control imposes others as to the arrangement of the conducting elements and their location relative to the vessel. Practical operation further demands the use of large currents with low losses, such as is offered

by conductive elements connected in parallel.

This invention contemplates a compliance with these requirements, by a placement of the conductive elements to generate a field with lines of flux distributed to give the desired heating effect. As the best means of disclosing the nature of the invention, whereby this object is accomplished, specific illustrations are given.

Restricting the consideration for the present to the effect of the shape of the vessel and the resulting conformation of the solenoid, a specific application of the invention to a hemi-spherical kettle will be described. Such a kettle is not heated uniformly with a solenoid whose elements form part of a conductor following the contour of the kettle and linked therewith through magnetic circuits of high reluctance, that is, where air or other material of low magnetic permeability forms part of the magnetic circuit; but this condition is corrected by the application of additional coils in approximate proportion to the degree of decrease in the slope of the kettle wall.

In explanation of this corrective action, it may be advanced that the currents induced in the kettle walls become less as the slope decreases, that is, as the contour approaches the horizontal; or, that the lines of flux, generated about the conductive elements and which permeate the kettle wall, become less in number with the decrease in slope due to the increased reluctance of the magnetic circuits linking the conductors with the kettle walls. In order to have sufficient lines of flux follow the kettle wall, they must be deflected in part toward each other or concentrated as the circular sectional area, or the peripheral path provided for the secondary currents, decreases, and the repellent action between them must be partially overcome. In other words, there is a disproportionate increased leakage of flux lines as the kettle area decreases, with induced electromotive forces decreasing at a greater rate than the resistances of the circuits for the secondary heating currents. Additional ampere-turns of primary current is therefore required to set up the induced currents necessary for uniform heating, and coils added in approxi-

mate proportions to the decrease in slope give this result.

Another specific illustration, restricted to the effect of the arrangement of the conductive elements, in which there is no change from the straight cylindrical solenoid to add complications, may also serve to elucidate the invention. It has been stated above that practical operation demands the use of conductive elements connected in parallel, but elements so connected are found to have most of the inducing current carried by the end elements and, as a result, they quickly become overheated. This condition is corrected, and flow of current in all the parallel connected elements, is obtained by adding at an end of the solenoid-like arrangement a few turns of a series coil which carries all the current that is subdivided between the parallel connected elements. This coil is connected in series with the parallel connected elements and is in inductive relation with the end portion of the solenoid-like arrangement of the parallel connected coil. This arrangement equalizes impedances by equalizing the magnetic field through all the coils. Such a series coil is added at each end, unless the inductive elements are located about a portion only, such as the lower part, of the kettle. In the latter case, the mass of metal in the kettle wall adjacent the end of the solenoid has a compensating effect thereon, and a smaller coil or, in some cases, none at all is needed at that end.

The explanation offered for the balancing effect of the series end coils is that the flux lines encircling the inductive elements at the end of the solenoid are relatively few in number, while they are relatively numerous about the intermediate elements. The impedance in the end coils is accordingly small and the current therefore flows principally in them. With the addition of a series coil at a remote end in inductive relation therewith, all the current is compelled to flow therethrough to create lines of flux proportionate to the number of turns. The result is that additional flux is provided for the end elements to equalize the field about the elements, and the current is then divided proportionately among them. If the impedances of the elements connected in parallel vary, due to differences in design and construction, the current will be correspondingly divided among them and the heating effect modified accordingly.

In order to effect a control of the heating over a range of temperatures, a plurality of groups of parallel-connected elements is provided. When these groups are connected in series, a current of low value passes through them and a low heat results. Connecting the groups in parallel permits a heavy flow of current and consequently a high heat.

Either of these effects are modified by placing in circuit additional conductors either in series or parallel. With a plurality of groups of parallel-connected elements, it becomes necessary to add a series conductor only at a remote end of the assemblage, the adjacent ends of the groups having a balancing effect similarly to the individual elements. The series conductor so added can be made of overlapping elements if it is in proximity to a portion of the vessel where a change in the sectional diameter occurs.

The invention is applicable for use with electrically conductive vessels of magnetic or non-magnetic material. With the former, the hysteresis effect is added to that of an eddy current effect common to both. To prevent the unnecessary escape of heat, insulation can be placed about the vessel and the conductive elements, or located between them. Means within or without the insulating jacket can be provided for cooling the conductive elements or the vessel or both.

For a more complete understanding of the invention, reference is to be had to the following description, and accompanying drawing, in which

Fig. 1 is a vertical section of a kettle and a continuous conductor about said kettle;

Fig. 2 is an enlarged detail of Fig. 1;

Fig. 3 is a wiring diagram therefor;

Fig. 4 is a vertical section of a round bottom kettle with a flat coil conductor associated therewith;

Fig. 5 is a vertical section of a kettle having flat induction coils connected in parallel and series and coils; and

Fig. 6 is a wiring diagram of the circuit incorporated in Fig. 5.

In the embodiment shown in Figs. 1, 2 and 3, an autoclave or vessel 1 is carried by channel beams 2, supported on columns 3, and has vertical straps 4 by which are carried porcelain insulators 5. These insulators support the conducting elements 6. The straps are connected at their upper ends by a ring 7 and have inwardly inclined portions 8 supporting insulators below the spherical bottom; and the portions 8 also carry an additional row of insulators 9, so that the conducting elements are doubled about the spherical portion. Enclosing the autoclave is a heat insulating casing 10, covered by a shell 11 and supported from a channel ring 12 carried by legs 13 to which the straps 4 are attached; and push doors 14 in the insulation give access to the interior. A bottom insulation 15 is supported on a plate 16 that is bolted to the ring 12 and has a sliding door 17 and removable insulation block 18.

In this installation the conducting elements form parts of one continuous conductor in two coils 19 and 20, one external of the other, and having leads 21 and 22 extending from the upper portion of the

casing. Included as part of the inside coil 19 is a portion returning upon itself about the curved bottom, where the insulators are doubled, and taking the place of the outside coil. The outside coil 20 is led through the outer row of insulators 9 and likewise doubled upon itself. An intermediate tap 23 leads from a mid-point of the outside conductor coil, and a lead 24 extends from the end of the inside coil. A tap 25 cuts out the portion of the outside coil passing through the insulators 9, and a lead 26 is the terminus of the outside coil. The control of current in these various portions of the coils by means of switches is clearly illustrated in Fig. 3.

With this arrangement, the primary current passes about the vessel through one coil, then in series through the four coils about the spherical bottom and into the other cylindrical coil. The mid-point tap permits cutting the upper end of the outer coil out of the circuit, or it alone can be in circuit; and similarly the leads 24, 25 and 26 permit the use or cutting out of sections of the coils about the lower portion.

In the modified embodiment shown in Fig. 4, flat vertical coils 27 connected in series are used, each coil consisting of a number of turns. The coil is placed about a hemispherical kettle 28 and, as the diameter of a horizontal section decreases, the coils are proportionately overlapped as shown. In this form, heat insulation 29 is placed between the kettle and the primary coils. The kettle and the coils are carried by a frame work 30; and a casing 31 encloses the coils.

Figs. 5 and 6 disclose another embodiment in which flat coils connected in parallel are used. A fusion pot 32 is carried by a framework consisting of legs 33 and channel rings 34, 35, and the same framework carries the flat coils 36. Insulation 37 separates the coils and the kettle. A casing 38 encloses the coils and air circulation within the casing is secured by a conduit 39, connecting a ventilation fan with a bottom cone-shaped plate 40. A deflecting cone 41 directs the air toward the coils. The air passes between the coils and out at the lower end of the casing 38.

The coils are connected in two groups, 42, 43, six coils being shown in each group connected in parallel. In series with each group at the outer or remote end is a coil 44 of four turns of heavy wire, and there are also two half coils 45, 46 at the outer remote end of each group. A double throw switch 47 connects each group to the feed mains 48, so that the groups can be connected in series or in parallel; and a single pole switch 49 throws the upper half coils into or out of circuit when the groups of coils are connected in series.

All the current in this form of the appa-

ratus passes to a group through the heavy wire coil 44, while the current through the coils, comprising a group, is subdivided between the coils. When the double pole switch 47 is down, the two groups are connected in parallel giving the greatest current flow and the highest heat; when the switch is thrown up and the two groups are connected in series, there is a smaller current flow and a low heat is the consequence. Further reduction in heat is obtainable by connecting in series the upper two half coils by means of the single pole switch 49 thrown into the upward position. The lower half coils 46 provide additional heat regulation and may be connected in the circuit if found necessary.

While the air circulation is disclosed by the embodiment illustrated in Figs. 5 and 6, it is readily applicable to the other forms. With the arrangement of the first embodiment the air, or other suitable cooling medium, is passed within the insulated casing. In this case both the vessel and the coils are cooled.

From the preceding, it follows that the invention provides for a distribution of the magnetic field and the induced currents in accordance with the heating effect desired. If a concentrated heat in a portion of the vessel or a uniform heat in a portion of variable formation is desired, the conductive elements are confined to or concentrated about that portion, the elements being overlapped or associated with a series conductor, depending upon the shape of the vessel and the wiring arrangement adopted. While the series conductor associating a group of parallel connected coils is shown concentrated at the end of the group, it can be of varying extent or connected with a continuous conductor in combination with the parallel-connected group. Where the group of parallel-connected coils extends only over a portion of the vessel, for instance, the lower end, the upper series coil may be of diminished size, or omitted, as the vessel wall extending beyond the coils has, to a greater or less extent, an effect similar to that of a series end coil on the flow of current through the parallel-connected coils.

The general application of the underlying principles of this invention to types of apparatus other than heating apparatus is clear. Accordingly the claims are not to be restricted to the specific embodiments, chosen to disclose the invention, but are to be given an interpretation commensurate with the field covered by them; and by the term "body" is to be understood a vessel or any arrangement, including coils constituting closed circuits and particularly annular-like arrangements, where in secondary currents may be induced for utilitarian purposes.

## I claim:

1. An electrical induction apparatus comprising in combination, an electrically conductive body, and a plurality of current conductive elements about said body, said elements being relatively more numerous about a portion of the body. 70
2. An inductive heating apparatus comprising in combination an electrically conductive vessel, said vessel having a contracted portion, and a plurality of current conductive elements about said vessel, said elements being relatively more numerous about the contracted portion of the vessel. 75
3. Electrical induction apparatus including in combination a body to be heated, current conductive elements for generating magnetic lines of flux permeating said body, and means in association with said elements for compensating for leakage of flux with respect to said body, said means comprising additional conductors adjacent to areas of magnetic leakage. 80
4. An inductive heating apparatus comprising in combination an electrically conductive vessel, said vessel having a contracted portion, and a conductor in inductive relation with said vessel, said conductor being in part concentrated about the contracted portion of the vessel. 85
5. An inductive heating apparatus comprising in combination an electrically conductive vessel, said vessel having a portion varying in section, and a conductor having a plurality of turns about said vessel, said turns varying inversely in number in approximate ratio with the variation in section. 90
6. An inductive heating apparatus comprising in combination an electrically conductive vessel, said vessel having a portion of decreasing sectional diameter, and a conductor having a plurality of turns about said vessel, said turns increasing in number in approximate ratio with the decrease in the sectional diameter. 95
7. An electrical induction apparatus comprising an electrically conductive body to be heated, a primary circuit composed of a plurality of current conductive elements forming a coil encircling said body, said elements being connected in parallel, and an additional current conductive element encircling said body and connected in series to said parallel connected elements, said additional element being in inductive relation to an end section of said coil for regulating the relative flow of current in said parallel connected elements. 100
8. An electrical induction apparatus comprising an electrically conductive body to be heated, a primary circuit composed of a plurality of current conductive elements forming a coil encircling said body and linked therewith through magnetic circuits of high reluctance, said elements being connected in parallel, and an additional current conductive element encircling said body and connected in series to said parallel connected elements, said additional element being in inductive relation to an end section of said coil for regulating the relative flow of current in said parallel connected elements. 105
9. An inductive heating apparatus comprising in combination, an electrically conductive vessel of varying diameter, conductive elements in inductive relation with said vessel, said elements varying inversely in concentration about the vessel according to its diameter, means for connecting two or more of said elements in parallel, and means associated with the parallel connected elements for regulating the relative flow of current in said parallel elements. 110
10. An inductive heating apparatus comprising in combination an electrically conductive vessel, a conductor in inductive relation with said vessel, heat insulating means associated with said vessel, and cooling means therefor. 115
11. Electrical induction apparatus including in combination a body, current conductive elements for inducing currents in said body, and means in association with said elements for simultaneously regulating the distribution of the currents induced within said body. 120
12. Inductive heating apparatus including in combination a vessel, current conductive elements for inducing heating currents in said vessel, and means in association with said elements for equalizing the distribution of the currents induced within said vessel. 125
13. Electrical induction apparatus including in combination a body, current conductive elements for generating magnetic lines of flux permeating said body, and means in association with said elements for compensating for leakage of flux with respect to said body. 130
14. Inductive heating apparatus comprising in combination a vessel and current conductive elements about the vessel for inducing heating currents in the vessel wall, said elements being arranged with relation to the vessel wall to regulate the distribution of the heating currents.
15. An inductive heating apparatus comprising in combination an electrically conductive vessel, a conductor in inductive relation with said body, heat insulating means positioned between said vessel and said conductor, a casing enclosing said conductor and spaced therefrom and means for circulating a fluid cooling medium over said conductors.
16. Inductive heating apparatus including in combination a vessel to be heated, current conductive elements for inducing heating currents in said vessel, and means in

association with said elements for equalizing the distribution of the currents induced within said vessel, said means comprising additional conductors adjacent to areas of diminished secondary current intensity.

17. An electrical heating apparatus comprising in combination an electrically conductive vessel and a primary coil having a plurality of conductive elements in inductive relation to the side walls of said vessel arranged more numerous about a portion of said walls so as to regulate the distribution of the currents induced within said vessel, a magnetic circuit surrounding said primary coil being provided by a wall portion of said vessel on the inner side of the coil and the atmosphere adjacent the outer side of said coil.

18. An electrical heating system comprising an electrically conductive body to be heated, a primary circuit for inducing currents in said body composed of a plurality of current conductive elements arranged along the side surfaces of said body in in-

ductive relation thereto, and a source of current for energizing said primary circuit, the ampere-turns of said primary circuit being greater about a portion of said surfaces to regulate the distribution of the currents induced in said body.

19. An electrical heating system comprising an electrically conductive vessel to be heated, a primary circuit for inducing currents in said vessel comprising a coil of current conductive elements encircling said vessel and arranged along the side walls thereof, said conductive elements being linked with said vessel through magnetic circuits of high reluctance, and a source of current for energizing said primary circuit, the ampere-turns of said primary circuit being greater in an end portion of said coil than in a central portion of the coil, to regulate the distribution of currents induced in said vessel.

In testimony whereof I affix my signature.

ARCHIBALD H. DAVIS, JR.