Sept. 22, 1931. P. H. BRACE 1,823,874

INDUCTION FURNACE

Filed April 23, 1930

Fig. 1

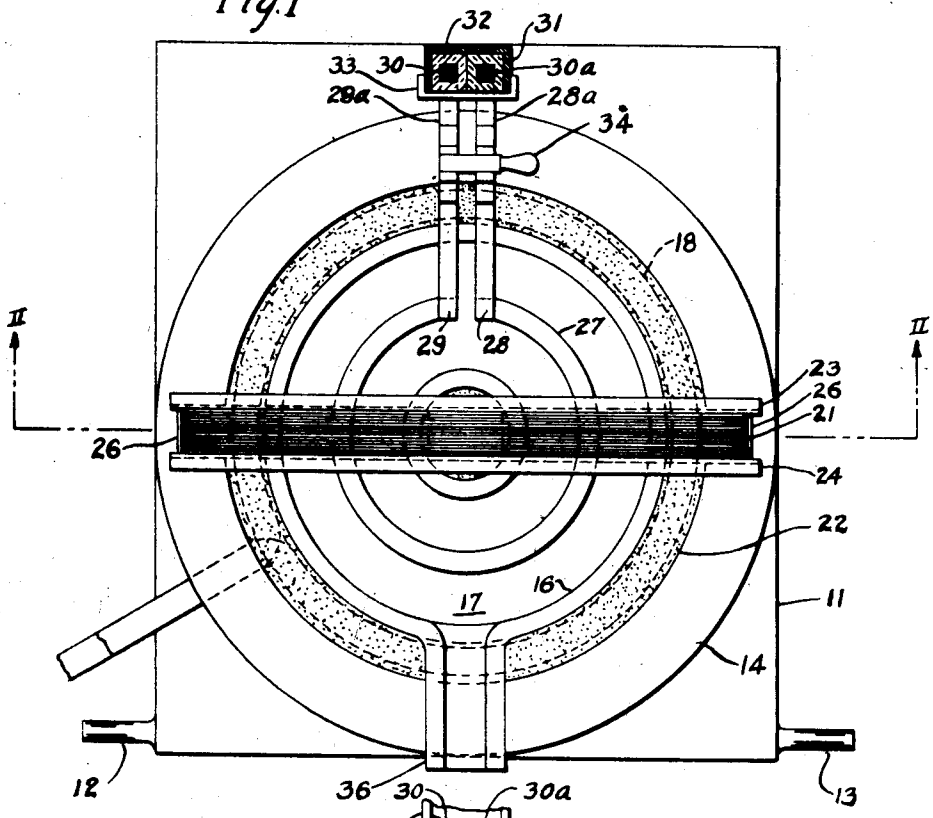
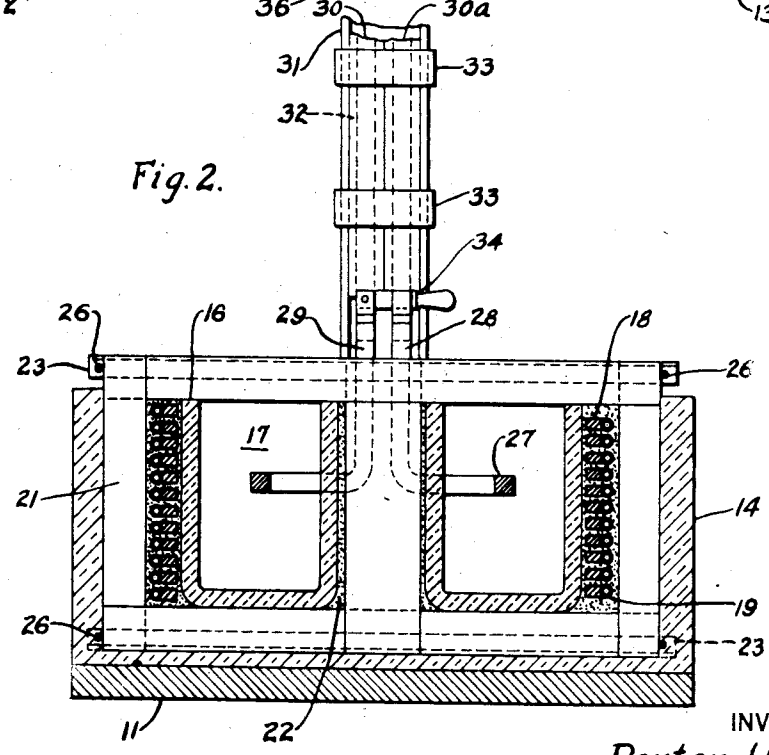



Fig. 2.




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# UNITED STATES PATENT OFFICE

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## INDUCTION FURNACE

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My invention relates to electric furnaces and more particularly to electric induction furnaces for melting highly refractory materials.

An object of my invention is to provide a compact, simple and highly efficient furnace structure for melting highly refractory material, such as glass.

Another object of my invention is to provide an induction furnace of the annular type with means for initially melting a portion of the charge.

Another object of my invention is to provide a furnace structure including an annular chamber for a charge to be melted, an energizing coil around the annular chamber and a source of alternating-current energy therefor, which elements shall be so correlated that the current density in the charge shall be substantially uniform throughout.

In practicing my invention, I provide an annular crucible, a laminated iron core therefor and an energizing coil extending around the outer periphery of the annular chamber, and a metal member of substantially annular form which may be initially located in the raw material in the annular chamber and be removed therefrom, and a source of supply of alternating-current energy, the frequency of which is such that substantially uniform current density is obtained in the molten material radially thereof.

In the single sheet of drawings:

Figure 1 is a top plan view of an induction furnace embodying my invention, a portion thereof being shown in horizontal section, and

Fig. 2 is a view, in vertical section, of the furnace shown in Fig. 1.

A base 11 for the furnace structure may be made of any suitable material and be provided with a pair of stub shafts 12 and 13 near one edge thereof to permit of mounting it for pivotal movements. I have not shown the other cooperating mechanism because it forms no part of my present invention.

A refractory structure 14, made of any suitable material, may be mounted on the base 11 and may be cylindrical in shape. A crucible 16, which is located within the refractory structure 14, has an annular chamber 17 for receiving a charge to be melted.

An energizing coil 18 is located immediately around the outer periphery of the crucible 16 and includes a plurality of turns of a fluid-cooled conductor 19 which may be of any suitable or desired shape but is here shown as including a solid current-conducting portion and a tubular fluid-conducting portion thermally associated therewith.

An iron core 21 is illustrated as being relatively small in radial thickness and, as extending not only around, but also through, the central portion of the crucible 16, and any desired or suitable construction thereof may be employed. The crucible 16 may be supported, in part, at least, by the laminated core 21 and also by a filling of a suitable granular material 22 which, in turn, is supported by the refractory structure 14. Elongated clamping members 23 and 24 may be provided adjacent to the top and the bottom portions of the core 21 and be held by bolts or rivets 26, or by any other suitable means.

A furnace of this type is well adapted to the melting of highly refractory material, such as glass, which has a relatively high resistance when cold, and, in order to start the melting operation, I have provided a metal member 27 of substantially annular shape to be located in the chamber 17. The annular member 27 is provided with upwardly-extending leg portions 28 and 29, horizontally-extending portions 28*a* and 29*a* and additional vertically-extending portions 30 and 30*a*, which latter are adapted to be adjustably mounted in a vertical standard 31, which may be of substantially channel shape in section. The leg portions 30 and 30*a* may be surrounded by electric-insulating material 32 in order to insulate them from the metal standard 31. Clamping members 33 may be provided against the otherwise open portion of the member 31, and any suitable clamping means may be provided in order that the member 27 may be located in any desired position between the top and the bottom of the chamber 17.

A short-circuiting switch 34 is operatively

associated with the horizontally-extending portions 28*a* and 29*a* in order that the member 27 may be short circuited or open circuited, as desired.

If it be assumed that the member 27 is located in either the position shown or near to the bottom of the chamber 17, and that a charge of raw material for making glass is located in the chamber, the switch 34 is moved to the position shown in Fig. 2 of the drawings and the coil 18 is energized from a source of alternating-current energy having a suitable frequency, as will be more clearly hereinafter set forth. It is obvious that heat will be generated in the member 27 to cause sufficient melting of the raw material to provide a small quantity of molten glass, which is sufficiently electric-conducting to carry sufficient current for melting additional raw material. The member 27 is then moved upwardly so that it will be located above the charge of raw material, and the switch 34 is moved to its open position to interrupt the flow of current therein.

The member 16 is provided with a pouring spout 36, in order that the molten material may be poured from the chamber 17.

Induction furnaces having annular chambers are well known but have always had the drawback that the pinch effect has been so pronounced, when relatively large amounts of electric energy were transformed into heat in a charge, as to interrupt the secondary circuit upon its becoming fluid, and this action has greatly limited the use of furnaces of this type. I desire to overcome this tendency to the interruption of the secondary circuit, and one of the first steps is to make the radial width of the chamber relatively large; to locate the energizing coil around this chamber and to energize it with alternating-current at such frequency as will effect substantially uniform current density in the respective annuli of the annular chamber, or, in other words, to ensure that the current density in a section of the bath, taken closely adjacent to the inner periphery of the bath, shall be substantially the same as that in a similar section taken at its outer periphery.

Messrs. Burch and Davis have discussed the general problem of annular furnaces of this kind in their book "An Introduction to the Theory of Eddy Current Heating", and a brief discussion of the mathematical theory upon which the selection of the frequency of the current supply is based is as follows:

Let $R_o$ = the outer radius, in centimeters, of annular chamber.

Let $R_i$ = the inner radius, in centimeters, of the annular chamber.

Let $r$ = resistivity of the charge in electromagnetic units.

Let $p = 2\pi \times$ frequency.

Let $f$ = frequency.

Let $B = \sqrt{\frac{r}{4\pi p}} = \sqrt{\frac{r}{8\pi^2 f}}$

Let R = effective resistance of the charge.

Let L = effective inductance of the charge.

It has been shown by Messrs. Burch and Davis that R and L are substantially constant until the value of the quantity $(R_o - R_i)/B$ is equal to, or slightly greater than, 1. When this equation is satisfied, the "skin effect" will not be pronounced, and the current density at the inner periphery of the charge will be relatively high because of the relatively small diameter of the charge at this part of the furnace. The use of an iron core has the result that the induced voltage at $R_i$ (or at the inner periphery of the chamber) is substantially the same as at $R_o$ (or at the outer periphery of the chamber), and hence, we have the result that the current density is higher at $R_i$ than at $R_o$. The same authors show also that when $(R_o - R_i)/B$ has a value much greater than three, the skin effect is very pronounced, and the current density is highest at the outer layers of the charge, that is, at $R_o$.

The current density in the charge will, therefore, be substantially the same in all of the peripheral layers when the value of the expression $(R_o - R_i)/B$ is between the values one and three.

We can, therefore, determine the optimum frequency to effect substantially uniform current density throughout the charge for given dimensions of an annular charge on the basis of no iron core and then reduce the value of the frequency thus calculated in case a laminated iron core is utilized. This is for the reason that a laminated iron core carrying the flux will reduce the magnetic reluctance of the path of the flux generated by the coil, and a larger number of lines of force will be interlinked with the charge, so that the same heating effect will be produced by a lower frequency of current, as would be produced by an energizing current of the higher frequency traversing the same coil when not provided with an iron core.

Let us assume that the optimum effect is obtained when $(R_o - R_i)/B = 1.5$.

Substituting for B, we have

$$\frac{(R_o - R_i)}{\sqrt{\frac{r}{8\pi^2 f}}} = 1.5$$

Simplifying we obtain

$$f = \frac{.0284 \times r}{(R_o - R_i)^2}$$

$$f = \frac{1.42 \times 10^8}{(R_o - R_i)^2}$$

when $r$ equals $5 \times 10^9$ E. M. U. as for glass.

This indicates that the optimum frequency of a current supply to obtain substantially uniform current density in an annular charge varies directly with the resistivity of the charge, and varies inversely with the square of the radial dimensions of the charge. The optimum frequency is, therefore, not dependent upon either the inner radius of the charge alone or upon the outer radius of the charge alone, but rather upon the radial width of the charge, and it varies inversely with the square of the radial width of the charge-containing chamber.

If we determine the optimum frequency for various radial widths of chamber from the last equation hereinbefore given, we shall obtain the following:

| $(R_o - R_i)$ | $f$ |
|---|---|
| 10 | 1,420,000 |
| 20 | 355,000 |
| 50 | 56,800 |
| 100 | 14,200 |
| 200 | 3,550 |

As was hereinbefore stated, the values for the optimum frequency of current supply are proper in the case of an ironless coil and furnace, and we have found it possible to reduce these frequencies to substantially one-tenth of these values when an iron core is used. Thus, it may be noted that, when a bath of 100 centimeters radial width is used, the optimum frequency for an ironless coil will be substantially 14,200 cycles per second and this may be reduced to 1420 cycles or thereabouts and still obtain substantially uniform current density in a charge of molten glass when using an iron core. It may be noted also that it is desirable to use the lower frequency because iron loss in the laminated core would be relatively high if the frequency of 14,200 cycles were to be used.

The device embodying my invention thus provides a relatively simple and compact furnace structure, including an annular chamber holding a charge and an energizing coil surrounding it, a laminated iron core covering a relatively small portion only of the furnace structure, and means for initially melting a portion of the charge to cause it to become electric-conducting, which means may be moved out of the charge, together with a source of supply at such predetermined frequency that the current density is substantially the same in various peripheral portions of the charge.

Various modifications may be made within the device embodying my invention without departing from the spirit and scope thereof and I desire, therefore, that only such limitations shall be placed thereon as are imposed by the prior art or are set forth in the appended claims.

I claim as my invention:

1. In an electric induction furnace, in combination with an annular crucible, an energizing coil surrounding the crucible and a magnetic core operatively associated with the crucible and the coil, a current-conducting annular member located in said crucible, and means for closing and opening an electric circuit therethrough.

2. In an electric induction furnace for heating initially granular material having high electrical resistivity when cold, in combination with an annular crucible, an energizing coil around the crucible and a magnetic core for the coil and the crucible, a current-conducting member of substantially annular shape located in said crucible and having leg portions extending away from its annular portion, a switch operatively associated with said current-conducting member to close or open an electric circuit therethrough, and means for adjustably supporting the current-conducting member in said crucible.

3. In an electric induction furnace for heating initially granular material having high electrical resistivity when cold, in combination with an annular crucible, an energizing coil around the crucible and a magnetic core for the coil and the crucible, a current-conducting member of substantially annular shape located in said crucible and adapted to melt a portion of a charge by heat generated therein by induction from said coil, a switch for establishing a closed electric circuit through said member to effect heating thereof by induction when the coil is energized, and means associated with said member to permit it to be moved within, and out of, the molten material.

In testimony whereof, I have hereunto subscribed my name this 18th day of April, 1930.

PORTER H. BRACE.