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HEAT TREATING APPARATUS

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Fig. 1.

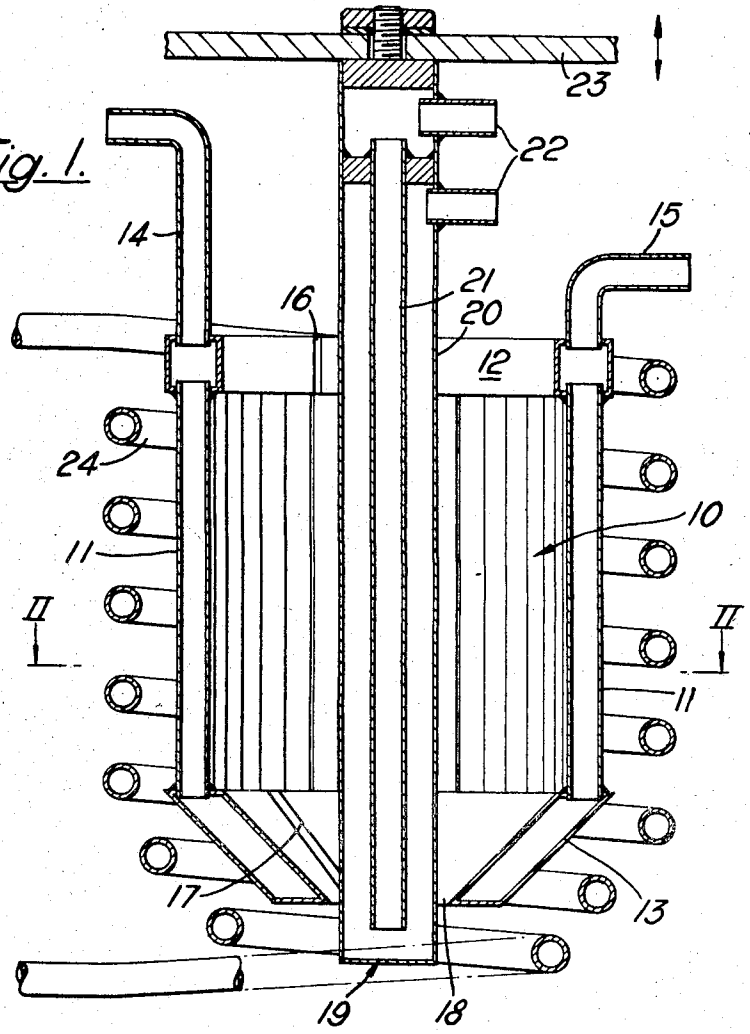
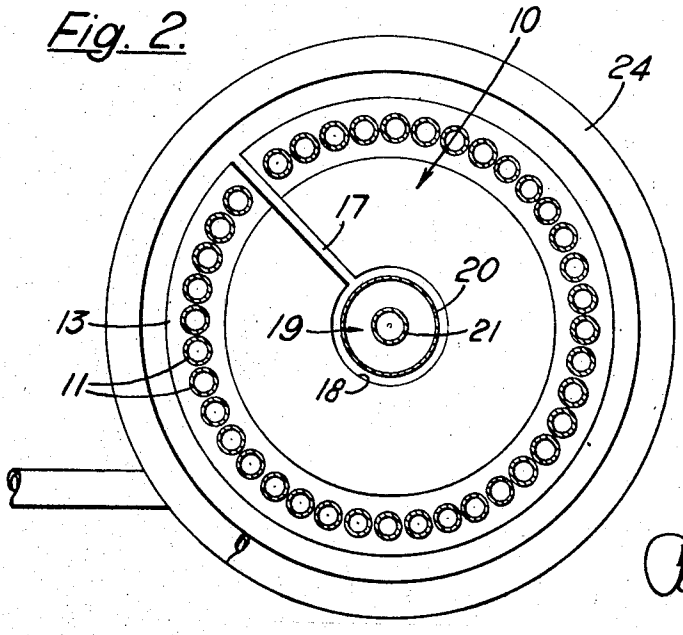


Fig. 2.



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HEAT TREATING APPARATUS

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ABSTRACT OF THE DISCLOSURE

Crucibles for melting highly reactive materials, such as titanium or nickel alloys, are constructed from metals having high electrical and thermal conductivity. The crucible walls are fluid cooled. The crucible has a pouring hole at its base closed by a movable fluid-cooled hollow copper plug. Use of the crucible results in the absence of charge contamination by the material of the crucible which is important in treatment of high-purity alloys, such as are used for gas-turbine blades.

The invention relates to apparatus for the heat treatment of electrically-conductive materials, having particular application to the melting or other heat treatment of materials that are highly reactive when hot and hence are particularly liable to contamination during treatment by the material of which a containing crucible is made.

According to the invention, apparatus for the heat treatment of electrically-conductive materials includes a crucible having in its lower part an opening which is normally obstructed by a movable plug extending through the crucible from the top opening thereof, the crucible walls and the plug being hollow and made of metal of high electrical and thermal conductivity, as hereinafter defined, and being provided with inlet and outlet points for the passage of cooling fluid through them, the apparatus including also means for connection to a source of high-frequency alternating current to establish circulating currents in the crucible walls and the plug and in a charge of conductive material if present within the crucible.

For the purposes of this specification a metal of high electrical and thermal conductivity is defined as a metal having a thermal conductivity of not less than 0.49 gram calories per sec. per cm.^{2} per (° C. per cm.) and a specific electrical resistance of not more than 2.665×10^{-6} ohms per cm.^{3} at 0° C. Silver, gold and copper are suitable metals, silver being preferred since it can be highly polished to reduce the loss of heat from the charge by radiation; alloys of these metals may be employed or alternately a surface coating of one metal such as silver on a member made of another metal such as copper. It is, of course, possible within these limitations for the members forming the crucible and plug to be made of differing materials.

In apparatus according to the invention, as defined above, when used to melt a charge of conductive material, the magnetic fields due to the circulating currents induced in the walls of the crucible and the plug and hence in the charge result in mutual repulsion between the charge and the adjacent surfaces of the crucible and plug. If the current density is sufficiently high the charge is forced away from the surfaces of the crucible and plug. The absence of actual contact between charge and crucible greatly reduces the heat loss from the charge and also virtually eliminates the possibility of charge contaminations by the crucible material. This effect also permits a highly convenient form of construction for the crucible

or the plug, or for both components, in which the crucible or plug wall is formed of a number of parallel tubes arranged sufficiently closely to prevent the passage of molten material between them.

The invention thus permits the construction of a crucible for use in such applications as the melting of highly reactive alloys, such as alloys of nickel or titanium, in which the charge can be removed from the crucible through an emptying aperture at its base without increasing the risk of charge contamination. Such an apparatus will now be described in more detail with reference to the accompanying drawings, in which:

FIG. 1 shows an axial cross-section of the apparatus and

FIG. 2 shows a transverse section of the apparatus on the plane marked II—II in FIG. 1.

The apparatus shown in the drawings provides a crucible of about 4 inches internal diameter capable of melting a charge of about two pounds weight of a nickel alloy. The walls of the crucible (which is indicated generally at **10**) consist of a series of parallel tubes **11** spaced with their axes vertical around the circumference of the crucible. The upper and lower ends of these tubes are connected to upper and lower header members **12** and **13** respectively; and inlet and outlet pipes **14** and **15** respectively connect to the upper header to permit the circulation of cooling fluid through the tubes **11**. In order to avoid providing a low resistance alternative path to the flow of fluid, and also to avoid providing a closed electrical circuit in the field of the induction coil, the upper header **12** is made in two halves, separated by small gaps **16**, one half-section being connected to half the tubes **11** and to the inlet connection **14** and the other half-section being connected to the remaining tubes **11** and to the outlet connection **15**. The fluid flow is thus from the inlet connection **14** into one half-section of the top header **12**, downwardly through half the tubes **11** to the lower header **13**, and from the header **13** upwardly through the remaining tubes **11** to the other half-section of the top header. The lower header **13** could be made in one continuous ring in so far as fluid flow considerations are concerned, but is in fact interrupted by a single gap **17** to break the electrical closed circuit.

The spacing between the adjacent tubes **11** is not critical, provided that it is insufficient for molten material to pass between them.

The lower header **13** of the crucible **10** is provided with a central pouring aperture **18** which during the melting of a charge is closed by a plug member **19** which extends downwardly from the top opening of the crucible to pass at least into and preferably through the pouring hole **18**. In the arrangement shown in the drawings the plug **19** consists of a thin-walled copper tube **20**, closed at both ends and provided with an internal tube **21** and fluid connection points **22** to permit the circulation of cooling fluid through it. At its upper end the plug **19** is supported by lifting means indicated diagrammatically at **23** by which it can be moved to clear the pouring aperture **18** in the base of the crucible. The degree of movement may be such that the plug **19** is withdrawn completely from the crucible, although this is not essential.

A primary induction winding **24** surrounds the crucible and at its lower ends extends sufficiently below the crucible to embrace the projecting end of the plug **19**. The coil **24** is made of copper tubing and is provided with connections for a source of radio-frequency alternating current and for cooling water in the usual way.

Energization of the coil **24** with high-frequency alternating current results in the setting up of circulating currents in the tubes **11** forming the crucible walls and also in the headers **12** and **13** and in the outer wall **20** of

the plug **19**. As a result corresponding circulating currents are induced in any charge of electrically inductive material present in the crucible, raising its temperature by eddy-current heating. The components comprising the crucible and the plug **20** are made of metal of high electrical conductivity, so that the resistive heating effect therein is negligible, and of good thermal conductivity so that excessive heating of the crucible and plug by heat loss from the charge is avoided. Limitations on the choice of suitable metals for the construction of the crucible and plug have been defined earlier in the specification. In the construction shown it is preferred to make the crucible members, that is to say the headers **12** and **13** and the tubes **11**, together with the outer shell **20** of the plug **19**, of silver-plated copper.

The relationship between the circulating currents set up in the charge on the one hand and in the crucible walls and the plug **19** on the other is such that mutual repulsion occurs between their associated magnetic fields. If the level of energization from the radio-frequency source is sufficiently high, actual physical separation of the charge from the adjacent surfaces of the crucible and plug occurs. The level at which this separation becomes significant is determined empirically for any particular form of crucible and nature and quantity of charge. With the crucible form shown satisfactory melting of a two-pound charge of nickel alloy is obtained at a power input of 35 killowatts at a frequency in the range 250 to 400 kilocycles per second. This physical separation of the charge from the crucible members means firstly that the entire mass of the charge is raised to the operating temperature, no cooler skin remaining between the molten charge and the crucible, and secondly that contamination of the charge by the material of which the crucible and plug are made is greatly reduced. In the casting of billets of a certain nickel-based alloy, required to have an extremely low impurity content, the use of zirconia crucibles resulted in between 70% and 80% of the billets having a prohibitively high level of contamination by the crucible material. When cast in the apparatus shown in the drawings and described herein the reject rate attributable to this cause was reduced to zero and no trace of crucible contamination could be detected in the billets.

The effect of mutual repulsion mentioned above also assists the surface tension of the molten charge in preventing the escape of material between the tubes **11** forming the crucible walls and also through the annular gap between the plug **19** and the lip of the pouring hole **18** at the base of the crucible. It is thus not essential for the plug **19** to be an accurate fit in the pouring hole **18**, and in fact a slight clearance is essential if the plug is not to short-circuit the isolation gap **17** in the lower header.

Molten material can be removed from the crucible by lifting the plug **19** so as to open the pouring aperture **18**. The energization of the primary winding **24** is maintained during pouring to ensure that the charge remains molten until clear of the crucible.

The arrangement shown in the drawings represents a simple embodiment of the invention in which the plug **19** is a simple tubular member provided with means for internal cooling. In an alternative construction which may be advantageous for crucibles of larger dimensions the plug **19** is itself built up in the same way as the crucible

10 from a series of closely-spaced parallel tubes connected by headers at their upper and lower ends. The operation of the crucible and plug in such an arrangement is identical with that already described. However, this alternative arrangement offers the possibility of increasing the rate of heating of the charge by providing a further primary winding within the enclosure by the spaced tubes of the plug. The supply of energy to this second coil may be controlled independently of that to the main external coil **24** to provide the most efficient heating effects.

References in this specification to the melting of electrically-conductive materials are not to be taken as excluding the use of the apparatus described for the melting or other heat treatment of materials which have appreciable conductivity only at elevated temperatures, since such materials can be pre-heated by any convenient means to a temperature at which the eddy-current heating phenomenon becomes effetcive.

It is to be understood that the foregoing description of specific examples of this invention is made by way of example only and is not to be considered as a limitation on its scope.

We claim:

1. Apparatus for the heat treatment of electrically conductive materials, comprising:
- a crucible having a wall formed by parallel lengths of tubes,
- the crucible having a top opening for inserting a charge of the electrically conductive material, and
- a lower opening for removing the electrically conductive material,
- the wall forming tube lengths being spaced sufficiently close side by side to prevent molten crucible charge material escaping therefrom,
- movable means including a plug extending through the crucible from the top opening thereof normally obstructing the lower opening,
- the tubes and the plug being hollow and made of metal of high electrical and thermal conductivity,
- means for passing cooling fluid through the tubes and plug, and
- primary coil means for connection to a source of high frequency alternate current to establish circulating currents in the tubes and plug and in the charge of conductive material within the crucible.

2. The apparatus according to claim **1** wherein the primary coil means comprises at least one primary induction coil surrounding the crucible.

3. The apparatus according to claim **1** wherein the plug is a hollow cylindrical member.

4. The apparatus of claim **1** wherein the plug is formed of a number of parallel tubes spaced sufficiently closely together to prevent the passage of molten material therebetween.

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