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P. J. CLOUGH ET AL

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HEAT RESERVOIR AND ELECTRODE FOR PRODUCTION
OF METALS IN SKULL TYPE FURNACE

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2 Sheets-Sheet 1

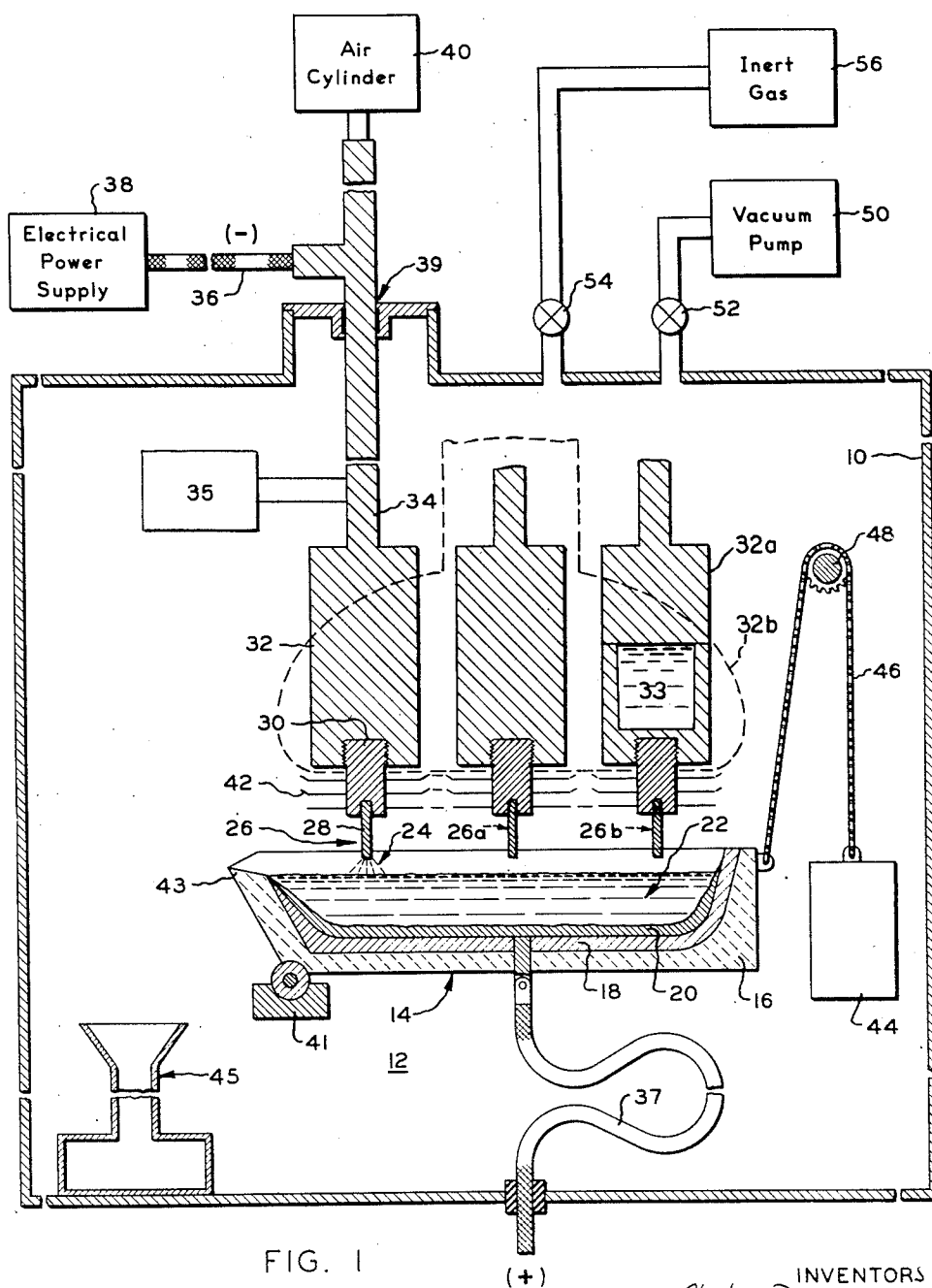


FIG. 1

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INVENTORS
Philip J. Clough
BY John L. Ham
David I. Sinizer
Oliver W. Hayes
ATTORNEY

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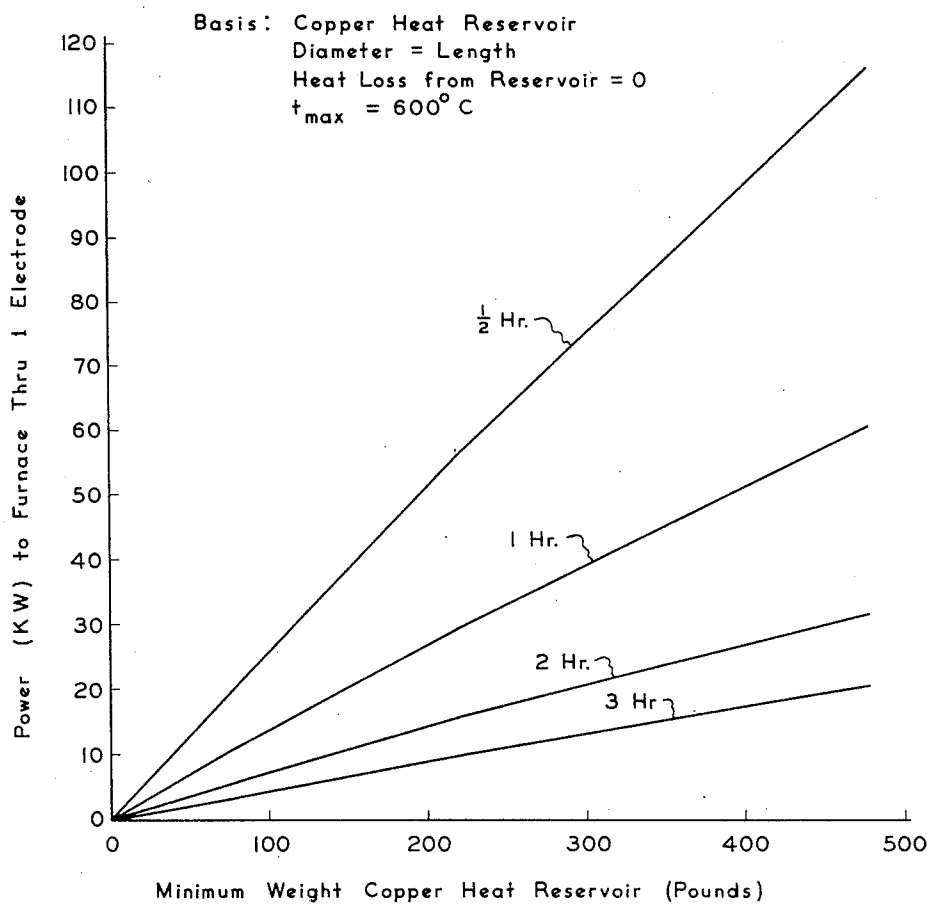


FIG. 2

INVENTORS
Philip J. Clough
BY John L. Ham
David I. Sinizer
Oliver W. Hayes
ATTORNEY

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HEAT RESERVOIR AND ELECTRODE FOR PRODUCTION OF METALS IN SKULL TYPE FURNACE

Philip J. Clough, Reading, John L. Ham, Wellesley Hills, and David I. Sinizer, Bedford, Mass., assignors to National Research Corporation, Cambridge, Mass., a corporation of Massachusetts

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8 Claims. (Cl. 13—14)

The present invention relates to arc furnaces and more particularly to arc melting furnaces which employ a "skull" of the metal to be melted.

A principal object of the present invention is to provide a skull melting furnace which has improved safety features.

Another object of the present invention is to provide a skull furnace employing non-consumable electrodes which do not require a fluid cooling system.

Another object of the present invention is to provide a vacuum skull furnace which can be economically constructed and operated.

Other objects of the invention will in part be obvious and will in part appear hereinafter.

The invention accordingly comprises the apparatus possessing the construction, combination of elements and arrangement of parts which are exemplified in the following detailed disclosure, and the scope of the application of which will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention, reference should be had to the following detailed description taken in connection with the accompanying drawings wherein:

Fig. 1 is a diagrammatic sectional view of one preferred embodiment of the invention; and

Fig. 2 is a graph showing the relationship between power input to the furnace and heat reservoir size.

In general, the present invention is directed to improved arc furnaces and particularly to a skull melting type furnace which is capable of melting given amounts of a reactive metal such as titanium or the like.

Skull melting is usually carried out under vacuum or inert gas conditions by subjecting the metal to be melted to an extremely hot electrical arc while the molten metal is supported in a solid skull of the same metal. The metal to be melted preferably serves as one of the electrodes for supporting an arc from one or more non-consumable electrodes. After sufficient melting, the molten metal is ready for pouring and casting. In order to prevent melting of the non-consumable electrode which supports the arc to the molten metal, a cooling arrangement must be provided. In the past, this cooling arrangement has taken the form of a fluid circulation system, the fluid generally being water. However, in such systems there has always been the danger that the cooling fluid would react with the molten metal. There were numerous ways in which this could happen, many of which were not preceded by any significant warning. As a result, there had always existed the threat of burn-outs and explosions which could cause disastrous injury to the furnace equipment and operating personnel.

It is the intention of the present invention to obviate the need for cooling fluids in such skull melting furnaces, particularly when melting reactive refractory metals like titanium and zirconium. In a preferred embodiment of the invention, the furnace comprises a vacuum-tight housing. A crucible means is provided within the housing in order to support a given amount of the refractory metal

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to be melted. This crucible preferably includes a solid skull of the refractory metal (e. g., titanium) to be melted, this solid skull remaining intact during the melting operation. The furnace also includes at least one arc-melting electrode for maintaining an arc to the metal to be melted within the crucible. This electrode is preferably maintained in heat transfer relationship with a heat reservoir means, which latter means preferably also constitutes an electrode support. In order to establish an electric arc at the electrode, the melting unit is provided with a source of electrical power. The heat reservoir means preferably comprises a solid body of material having a high degree of thermal and electrical conductance. In the preferred embodiments, such a body comprises copper, silver or the like. The reservoir means must be capable of absorbing large quantities of heat, since it has been experimentally determined that the amount of power which must be absorbed during arc melting is on the order of about 20 percent of the total amount of power fed into the furnace. The furnace is thus inherently lacking in complete utilization of power, and the amount of power fed to the furnace will be somewhat in excess of the amount of power required to melt a given amount of metal.

The general heat flow into a copper mass of given dimensions can be calculated with considerable exactness (see Formula 1, page 104, Conduction of Heat in Solids, Carstow and Jaeger, Oxford Press, 1948). From such calculations, the temperature drop and ultimate temperature of a copper heat reservoir of known dimensions can be approximated for various times and rates of power input to the furnace. Certain calculations have been made as to the requisite minimum weights of copper heat reservoirs for given power input for periods of 1/2 hour, 1 hour, 2 hours and 3 hours. Since a heat reservoir having a length equal to its diameter approaches the optimum shape, these calculations are based on a reservoir whose diameter equals its length. The assumptions are made also, for simplicity of calculation, that no heat is lost from the reservoir and that the maximum temperature of the reservoir is 600° C. The results of these calculations are plotted in Fig. 2 which is a graph showing the weight of copper (in pounds) required for a given furnace power input for a given period of time.

From an examination of Fig. 2, it can be seen that the requisite size of the heat reservoir is a function of both the rate of power input and the time of power input at a given rate. Since experience has shown that a minimum power input to the furnace of about 25 kw.-hr. is required to melt one pound of titanium, the minimum weight of the heat reservoir can be shown to be about twice the weight of the titanium to be melted. Since these calculations largely ignore heat losses through the solid titanium skull, a preferred minimum size of heat reservoir is one having a weight at least four times the weight of the titanium to be melted. In practice, deviations from the optimum shape of the electrode are often dictated by the space limitations in the furnace. Accordingly, as the length of the heat reservoir is increased with respect to its diameter, its efficiency as a heat sink is decreased due to the larger temperature differential which will exist along its length under a given rate of heat input at the end supporting the electrode. Accordingly, the mass of the heat reservoir is preferably made as much as ten times as large as the mass of the titanium to be melted. Even larger relative sizes of heat reservoir can be employed, but not much in safety is gained by going to larger heat reservoirs, unless long holding periods and/or high degrees of superheat for the molten metal are required.

When it is desired to melt metals such as titanium and zirconium, the electrode is preferably constructed of a

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material having a melting point on the order of 2500° C. and above. Otherwise, the electrode could not support an electrical arc hot enough to melt appreciable quantities of titanium or zirconium. In one preferred embodiment, the electrode comprises tungsten, which has excellent electrode characteristics.

When a high-temperature arc of the type required for melting titanium is employed, the transfer of heat by radiation can be very substantial unless shielding is provided. Accordingly, to prevent this transfer of heat to that part of the heat reservoir closest to the electrical arc, a radiation shielding means is preferably located between the reservoir and the arc. This radiation shielding is preferably formed of a material having a melting point on the order of above 2500° C. In a preferred embodiment, the shielding means consists of a series of annular discs of molybdenum at the bottom of the reservoir. The over-all width of the shielding means is on the order of the diameter of the heat reservoir in the illustrated preferred embodiment.

Referring now to Figs. 1 and 2, it can be seen wherein the above described features of the invention are embodied in the illustrative furnace construction. A furnace 10 is provided with a vacuum-tight housing which furnishes a chamber 12 capable of being evacuated to a low free-air pressure on the order of a few microns Hg abs. the "skull" melting crucible is generally indicated at 14 as comprising an outer support of a refractory material 16 and an electrically conducting crucible 18 (preferably of a carbonaceous material such as graphite) which defines the outer limit of the solid titanium "skull" 20. This "skull" 20 in turn confines a deep pool of molten titanium 22, which pool is maintained molten by means of one or more arcs 24. A plurality of electrodes preferably is provided, only one of these electrodes being shown in detail, the electrode assembly being generally indicated at 26 as including an electrode tip 28, a tip support 30 and a massive heat reservoir 32. This assembly is preferably supported by means such as a rod 34 extending to the outside of the furnace through a vacuum-tight seal 39. This rod 34 preferably serves additionally as a current lead, being connected to a conductor 36 from an electrical power supply such as a welding generator, indicated at 38. A moving mechanism such as an air cylinder 40 is preferably provided for adjusting the vertical position of the electrode assembly 26. This mechanism is preferably arranged so that the electrode assembly 26 can be lifted out of the way when tilting of the crucible is to be accomplished. The electrode tip 28 is preferably maintained at a minus potential, while the carbon crucible, and the molten titanium supported thereby, is maintained at a positive potential by means of a lead 37 extending through the furnace wall. In order to prevent, as much as possible, transfer of radiant heat from the arc and the molten titanium to the heat reservoir 32, there is provided a plurality of heat shields 42 adjacent the bottom of the heat reservoir 32. As indicated, these radiation shields are preferably carried by the electrode tip support 30.

In order that the crucible may be tilted to permit pouring of the molten titanium therefrom, it is preferably supported on a trunnion 41 so that molten titanium may be poured from a crucible lip 43 into a mold schematically indicated at 45. To assist in tilting the crucible, a counterweight 44 is preferably included, this counterweight being provided with a chain 46 which is connected to the crucible and passes over a driven sprocket 48.

In the operation of the device illustrated above, a charge of solid titanium is provided within the skull 20 and the furnace is evacuated to a low free-air pressure (on the order of a few microns Hg abs.) by means of a vacuum pump 50. When essentially all of the air has been pumped out of the system and it has been sufficiently outgassed to remove residual water vapor and the like, the valve 52 is closed to isolate the vacuum pump-

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ing system from the chamber. A valve 54 is then opened so as to permit introducing a partial pressure (on the order of 200 mm. Hg abs.) of an inert gas such as argon from a supply 56 thereof. The electrode assemblies 26, 26a and 26b are then moved down into position. Equally, a full atmosphere (760 mm. Hg abs.) of inert gas may be employed. The solid titanium is then melted by means of one or more arcs playing on the surface thereof. If desired, alloying additions can be made so as to furnish any predetermined melt composition. During melting, the vertical position of the electrode tips 28 may be suitably adjusted by the air cylinder. Equally, a transverse adjusting mechanism 35 may be provided to permit transverse relative movement between the crucible and one or more of the electrodes. When the melting has been completed, the electrode assembly is moved upwardly to the top of the furnace so as to permit free tilting of the crucible with pouring of the molten titanium therefrom into a suitable mold.

In a preferred embodiment of the invention, the crucible 18 is preferably formed of a material such as carbon or graphite, since either is an electrical conductor and will not melt at the high temperatures required for melting the titanium. The titanium "skull" is from one to four inches thick (depending on the size of the melt) so as to obviate the possibility of carbon contamination of the molten titanium confined with the solid titanium skull. The electrode tip 28 is preferably formed of a high-melting metal such as tungsten, while the electrode tip support 30 may be formed of tungsten or a more easily machineable metal such as molybdenum. Similarly, the radiation shields 42 are preferably formed of molybdenum. As mentioned previously, the heat reservoir 32 preferably comprises a massive block of copper. Obviously, it can be formed of several pieces as indicated at 32, and portions thereof can be formed of metals other than copper, provided that the total reservoir has sufficient heat capacity and conductivity. If desired, portions of the heat reservoir might even be formed of a low-melting metal such as Wood's alloy and the like as indicated at 32.

Obviously, numerous alternative arrangements of equipment can be provided without departing from the scope of the invention. For example, the heat reservoir, while preferably rigidly attached to the electrode support 30, might be attached by a liquid metal junction which would permit some movement between the two elements while still permitting transfer of heat therebetween. Equally, the arc current need not pass through the heat reservoir 32. It can be directly led to the electrode support 30. However, the arrangement shown is highly desirable from the standpoint of simplicity of construction and ease of operation.

While one preferred form of heat reservoir has been illustrated in the drawing, numerous modifications thereof can be provided without departing from the scope of the invention. For example, the heat reservoir 32 can be a single large hemisphere (as shown at 32b in dotted lines) which supports all of the electrodes 26, 26a and 26b. In this case (as shown in dotted lines) the heat shields 42 can extend completely across the bottom of the hemisphere to prevent excess radiation of heat from the arcs and hot molten metal to the heat reservoir.

Numerous additional changes in the processing techniques can also be employed. For example, the pressure in the furnace may range from the lowest pressure which the vacuum pumps will maintain to pressures somewhat above atmospheric, obtained by admitting a positive pressure of an inert gas such as argon after evacuation of the furnace and shutting off the valves to the vacuum pumps.

Since certain changes may be made in the above apparatus without departing from the scope of the invention herein involved, it is intended that all matter contained in the above description, or shown in the ac-

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companying drawings, shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. An improved arc furnace for skull melting a reactive metal, such as titanium and the like, said furnace comprising in combination a gas-tight housing, a metal-holding crucible of a size sufficiently large to hold a predetermined quantity of a molten reactive metal within a solid skull of said reactive metal, at least one electrode means for creating a metal-melting arc to the metal to be melted in the crucible and a solid heat reservoir means in heat transfer relationship to the electrode means, said heat reservoir means having sufficient mass to store on the order of 20 percent of the amount of heat required to melt said predetermined quantity of metal, the mass of said solid heat reservoir means being at least four times the mass of said predetermined quantity of molten metal.

2. The apparatus of claim 1 wherein said heat reservoir means comprises copper.

3. The apparatus of claim 2 wherein said electrode means comprises a tungsten tip.

4. An improved arc furnace adapted for skull melting a given amount of titanium or like refractory metal, said furnace comprising in combination a housing, a crucible, an electrical power source, an electrode support means comprising material having a high degree of thermal and electrical conductance, said electrode support forming a heat reservoir means capable of absorbing on the order of 20 percent of the total heat supplied to the furnace to melt said amount of refractory metal, said reservoir means having a large cross section to permit distribution of the absorbed heat substantially throughout its entire mass, an electrode means comprising an electrically conductive material having a melting point on the order of above 2500° C. capable of supporting an electrical arc, and a radiation shielding means located between said reservoir means and said arc.

5. An improved arc furnace adapted for skull melting a refractory metal such as titanium and zirconium, said furnace comprising in combination a housing, an electrical power source, a crucible means, an electrode support means constituting a massive member having a relatively large cross section, said electrode support means comprising a material having a high degree of electrical and thermal conductance, an electrode comprising material

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having a melting point on the order of above 2500° C., said electrode having a relatively small cross section, a radiation shielding means comprising material having a melting point on the order of above 2500° C., said radiation shielding means comprising annular members extending outwardly from said electrode and shielding the end of the electrode support means from radiation from an arc at the tip of the electrode.

6. An arc melting furnace for skull melting a given amount of a refractory metal such as titanium or zirconium, said furnace comprising in combination a vacuum-tight housing, a crucible means, an electrical power source, a heat reservoir means constituting an electrode support means and comprising material of high electrical and thermal conductance, said heat reservoir means weighing on the order of between four to twenty times the weight of said amount of refractory metal to be melted, an electrode comprising electrically conductive material having a melting point on the order of above 2500° C., and a radiation shield means located between said heat reservoir means and an arc at the end of the electrode.

7. The apparatus according to claim 6 wherein the said heat reservoir means has a configuration capable of distributing said absorbed heat throughout said reservoir means so as to maintain all of the reservoir means at a temperature below its melting point.

8. The apparatus according to claim 6 wherein the said heat reservoir means has a configuration capable of distributing said absorbed heat throughout said means so as to maintain all of the reservoir means at a temperature below a temperature where deformation of said reservoir means takes place.

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