Feb. 19, 1963 H. R. SMITH, JR 3,078,326

ELECTRONIC FURNACE WITH SHIELDED FEED

Filed Dec. 28, 1959 2 Sheets-Sheet 1

FIG-1

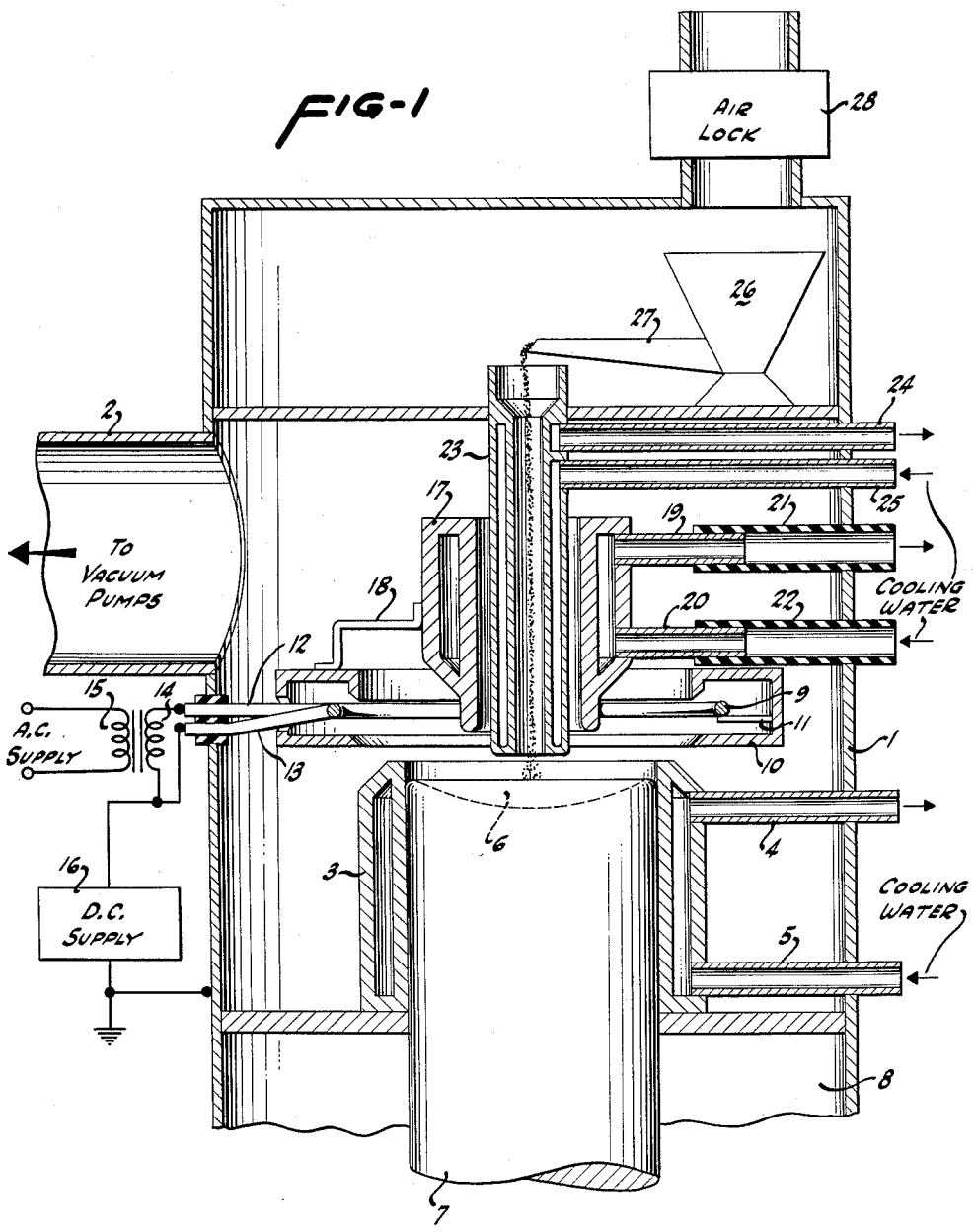

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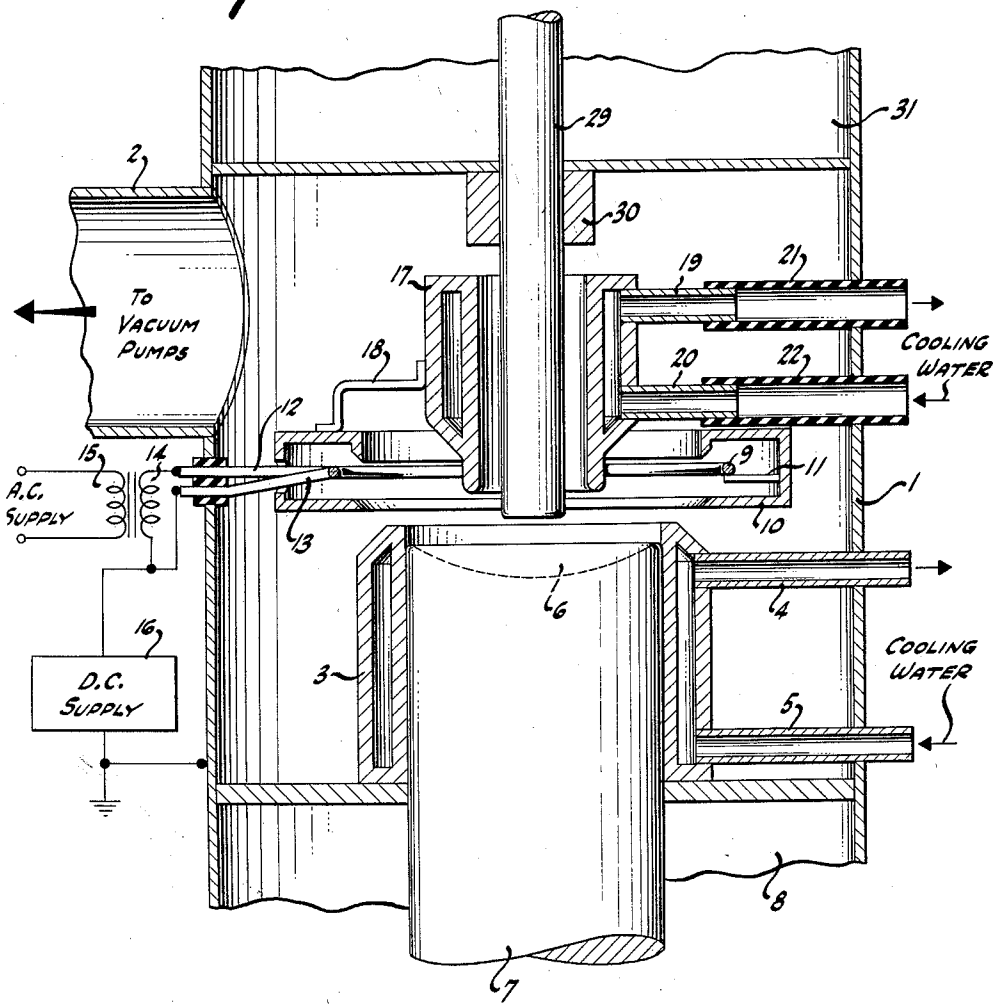
FIG-2



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United States Patent Office 3,078,326 Patented Feb. 19, 1963

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ELECTRONIC FURNACE WITH SHIELDED FEED

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Filed Dec. 28, 1959, Ser. No. 862,128
5 Claims. (Cl. 13—31)

This invention relates to the melting and casting of materials by electron-bombardment heating in a vacuum, and particularly to improvements for continually feeding material into a crucible wherein a molten pool of the material is maintained by continuous electron bombardment from above.

Many metallic, refractory materials emerge from their extractive metallurgy process as very fine powders. Powders of materials having high melting temperatures are difficult to reduce to ingot form by conventional methods. For example, arc melting is unsatisfactory because the arc tends to blow the powders about and provide very poor overall melting efficiency; and induction units of standard frequencies will not couple electrically with loosely compacted powders. Hence, it has been standard practice heretofore to compress and sinter refractory powders into bars, or the like, prior to melting. Such techniques are both expensive and inefficient.

Electron-bombardment heating can melt powders efficiently—even in the finest powders, each grain is very large in comparison to an electron, and the powder makes a very satisfactory bombardment-heated anode. However, in continuous processes a difficulty is encountered in the continual supply of powder to a crucible or receptacle for holding it while it is being melted. The reason for this appears to be that the individual grains of powder become electrically charged and are acted upon by electrical forces as they pass through the electric field associated with the electron-bombardment system. Also, the melting powders may evolve considerable quantities of gaseous matter into the vacum system. As a result, the powder being fed into the crucible may be badly dispersed, resulting in serious loss of powder as well as interference with proper operation of the electron-bombardment heating system.

A somewhat different problem is encountered when solid bars, or the like, of melt stock are fed into the crucible. In this case there may be a tendency for the electron beam to climb up the rod of melt stock, or to jump erratically between the rod of melt stock and the molten pool in the crusible. In the past this has necessitated melting the rod of melt stock a considerable distance above the top of the crucible, often by means of a separate electron-bombardment system, permitting the molten material to fall into the molten pool which is maintained within the crucible. This can cause splashing and spattering of molten material, which is not only wasteful, but also builds up unwanted deposits of metal on the electron guns.

The present invention solves both classes of problems discussed above by providing a tubular shield, of small diameter relative to the crucible, having an open, lower end adjacent to and approximately centered over the open top of the crucible. Thus, a substantial annular clearance remains between the tubular shield and the crucible. A stream of electrons is directed through this clearance downward into the open top of the crucible, for heating the material in the crucible and maintaining the necessary molten pool therein. The material to be melted is continuously supplied downward through the tubular shield, and in this way is protected both from direct action of the electron beam and from the dispersive forces associated with the electric field.

The invention may better be understood from the following illustrative description and the accompanying drawings.

FIG. 1 of the drawings is a somewhat schematic, vertical section of a furnace for melting powdered material;

FIG. 2 is a somewhat schematic, vertical section of a furnace for melting bar stock.

Referring to FIG. 1 of the drawings, a vacuum chamber 1 is continuously evacuated to a high vacuum, i.e., less than one micron Hg absolute pressure, by connection through duct 2 to conventional vacuum pumps of appropriate capacity. Within the vacuum chamber, there is an annular, copper, water-cooled crucible 3. This crucible has open top and bottom ends for the casting of continuous rods or ingots by the well-known skull-casting technique. The copper crucible is water-jacketed, as shown, and cooling water is continuously circulated therethrough by way of pipes 4, 5 connected to any appropriate source of cooling water, whereby the material immediately adjacent to the crucible walls is maintained below its melting temperature, and therefore solidified. A pool 6 of molten material rests in a skull at the top of the solid ingot, and the ingot is cast continuously by solidification of the material at the bottom of the pool. The rod-like cast ingot 7 can thus be continually withdrawn through the bottom of the annular crucible, generally into an air lock 8, and then cut off into appropriate lengths, as desired.

The pool 6 of molten material is maintained by continuously bombarding its upper surface with a stream of electrons from an electron gun disposed above the open top of the crucible. In its usual form, the electron gun comprises an annular, thermionic cathode 9, usually a horizontal loop of tungsten wire, and an annular, metal focusing ring 10 of inwardly opening, generally channel-shaped cross-section, as shown. The focusing ring 10 is maintained approximately at cathode potential, e.g., by the metal strap 11 connecting the focusing ring to the cathode loop. This serves to focus the electrons emitted by the cathode into a conelike beam directed inwardly and downwardly into the open top end of crucible 3.

The two ends of the cathode loop are connected through leads 12 and 13 to the secondary 14 of a transformer having a primary 15 connected to a suitable alternating-current supply, which provides alternating current through the cathode loop to heat the same to a temperature at which substantial thermionic emission of electrons occurs. The D.C. power supply 16 maintains the cathode and focusing ring at a potential of several thousand volts negative relative to the grounded crucible 3 and the material therein. Hence, the molten pool 6 acts as an anode at a positive potential of several thousand volts relative to the cathode. Electron bombardment of this anode provides sufficient heat to maintain the molten pool at the desired size.

A tubular shield 17 has its open, lower end approximately centered over the open top of crucible 3, as shown. This shield is of substantially smaller diameter than the crucible, so that the open, lower end of shield 17 overlies less than half the open area at the top of the crucible, leaving a substantial annular clearance between the shield and the crucible. Shield 17 is maintained approximately at cathode potential, e.g., by metal strap 18 connecting the shield with the focusing ring 10. Hence, there is relatively little electron bombardment of the shield 17—on the contrary, the shield helps to focus the beam and force it down into the open top of the crucible, so that the beam will be most effectively used in bombarding the upper surface of the pool 6.

Because the lower end of shield 17 is quite close to the hot, molten pool 6, the shield should either be of a

high-melting point, refractory material, e.g., tungsten, or provision should be made for cooling the shield 17. Cooling is also desirable in that it tends to inhibit arcing between the anode and shield 17, which of course is undesirable. In the illustrated embodiment, the shield 17 is cooled by providing it with a water-jacket, as shown, to which cooling water is circulated through the pipes 19 and 20. Because the shield 17 is at a high negative potential relative to the grounded walls of the vacuum enclosure, it must be electrically insulated therefrom. This is accomplished by using insulating sections of pipe 21, 22 and employing a low-conductivity cooling water. When cooled in this manner, the shield 17 may advantageously be made of copper.

Feed tube 23 extends vertically through shield 17 and has its lower end positioned just above the open top of crucible 3, as shown. Feed tube 23 is in spaced, coaxial relation to shield 17, with sufficient clearance therebetween to maintain the high voltage employed for electron bombardment, shield 17 being at cathode potential and tube 23 being at ground or anode potential. Tube 23 should be of high melting-point, refractory material; or, alternatively, it may be of a conductive material, such as copper, provided with a water jacket, as shown. Cooling water is circulated to the water jacket around feed tube 23 through pipes 24 and 25.

A supply of the powdered material that is to be melted is maintained within hopper 26, from which it is fed at a controlled rate by a conventional vibrator apparatus through the feed chute 27. Thus, a steady or intermittent stream of powder, as desired, and generally under control of the operator, falls from the end of feed chute 27 into the open upper end of feed tube 23. The powder readily passes through the feed tube under the influence of gravity and falls into the center of molten pool 6. Thermal gradients in the molten pool keep it continuously stirred, and thus the powder spreads out over the surface of the pool and is rapidly melted, both by contact with the molten material surrounding it and by direct bombardment from the electron beam. As the powder melts it may evolve considerable quantities of gaseous matter. This presents no particular problem, provided the operator regulates the feed rate to prevent too thick a layer of powder accumulating on the surface of the molten pool. The hopper 26 can be refilled from time to time, as desired, through the air lock 28.

It will be noted that the arrangement illustrated and described feeds the powder to be melted directly into the center of the molten pool within the crucible with minimum exposure of the powder to dispersive forces. The feed tube 23 is at anode potential, and its lower end is quite close to the top of crucible 3. Therefore, powder falling from the lower end of the feed tube into the crucible is effectively shielded from the major part of the strong electric field between the crucible and the cathode of the electron-bombardment system. As the powder spreads out over the top of the pool, it is bombarded by high-velocity electrons and is readily melted. This occurs, however, with the powder spread out over the pool in a fairly thin layer, so that the evolution of gaseous matter by the melting powder has minimum dispersive effect upon the powder remaining unmelted—the evolved gases readily escape with minimum obstruction into the high vacuum system.

The shield 17 protects the feed tube 23 from electron bombardment. If shield 17 were not employed, tube 23—being at anode potential—would attract a considerable proportion of the electron beam and result not only in wasted electrical power but also in difficulties in cooling tube 23 and in providing sufficient heat to the pool 6 to maintain a pool of adequate size in large-scale operations.

Referring to FIG. 2, the furnace for melting bar stock is essentially like that for melting powders, except that the bar of melt stock 29 replaces the feed tube 23. Bar 29 passes downward through tubular shield 17, as shown, in spaced, coaxial relation therewith and with sufficient clearance to withstand the high voltage applied to the electron bombardment system. The melt stock 29 is grounded through the supporting apparatus and thereby maintained at anode potential. Hence, there is no voltage between the lower end of bar 29 and the molten pool 6 within the crucible. A guide collar 30 holds the bar 29 in position, and the bar of melt stock can be raised and lowered, at will, by sliding it up and down within the guide collar 30. Generally, an upper air lock 31 is provided for the insertion of successive bars of melt stock without breaking the vacuum in the main vacuum chamber 1. Obvious mechanical devices may be provided for handling and feeding in the bars of melt stock by remote control.

In operation, the electron gun bombards and maintains the molten pool 6. The tubular shield 17 prevents any substantial bombardment of the bar 29 of melt stock. Instead, bar 29 is fed in until its lower end is sufficiently close to the molten pool to be melted away by its proximity to the hot melt. Hence, the distance that the molten material falls in dropping from the bar 29 into the pool is quite small, and splashing and spattering of molten material are minimized.

It will be understood that the specific embodiments illustrated and described are merely exemplary, and that numerous changes and modifications can be made without departing from the true scope of the invention defined by the claims.

What is claimed is:

1. An electron-bombardment melting and casting furnace comprising a crucible having an open top, a tubular shield having an open lower end adjacent to and approximately centered over said open top, said lower end overlying less than half the area of said open top, leaving a substantial annular clearance between the crucible and the tubular shield, means for supplying the material to be cast downward through the shield into said crucible, and an electron gun set to direct a stream of electrons downward through said clearance into said crucible for bombarding and heating the material therein.

2. A furnace as set forth in claim 1, said electron gun consisting of a filamentary loop, thermionic cathode, and a focusing ring of inwardly opening, channel-shaped cross-section, said cathode being within said focusing ring and both encircling said tubular shield, connections for maintaining said cathode, focusing ring, and shield at approximately the same electric potential, and D.-C. supply means for maintaining said crucible at a positive potential relative to the cathode.

3. An electron-bombardment melting and casting furnace comprising a crucible having an open top, a tubular shield having an open lower end adjacent to said open top, said lower end being smaller than said open top, leaving a clearance between the crucible and the shield, a feed tube extending longitudinally through said tubular shield, means for supplying material to be melted and cast through said feed tube into said crucible, and an electron gun set to direct a stream of electrons downward through said clearance into said crucible for bombarding and heating the material therein.

4. An electron-bombardment melting and casting furnace comprising an annular metal crucible having an open top, said crucible having a water jacket, means for circulating cooling liquid through said water jacket, a vertical, tubular, metal shield having an open lower end adjacent to and approximately centered over said open top of the crucible, said lower end of the tubular shield overlying less than half the area of said open top of the crucible, leaving a substantial annular clearance between the crucible and the tubular shield, a vertical, metal feed tube extending downward through said tubular shield in spaced, coaxial relation thereto, means for supplying powdered material to be melted and cast downward through said feed tube into the crucible, an electron gun set to direct a stream of electrons downward through

said clearance into said crucible for bombarding and heating the material therein, said gun having a thermionic cathode, D.-C. supply means for maintaining said crucible at a positive electric potential relative to the cathode, connections for maintaining said tubular shield at approximately the same electric potential as said cathode, and connections for maintaining said feed tube at approximately the same electric potential as said crucible.

5. An electron-bombardment melting and casting furnace comprising an annular, metal crucible having an open top, said crucible having a water jacket, means for circulating cooling liquid through said water jacket, a vertical tubular metal shield having an open lower end adjacent to and approximately centered over said open top of the crucible, said lower end of the tubular shield overlying less than half the area of said open top of the crucible, leaving a substantial annular clearance between said crucible and tubular shield, means for supporting a bar of the material to be cast vertically within and in spaced coaxial relation to said tubular shield, said

bar extending movably downward through the open lower end of the shield for supplying said material into the crucible, an electron gun set to direct a stream of electrons downward through said clearance into said crucible for bombarding and heating the material therein, said gun having a thermionic cathode, D.-C. supply means for maintaining said crucible at a positive electric potential relative to the cathode, connections for maintaining said tubular shield at approximately the same electric potential as said cathode, and connections for maintaining said rod at approximately the same electric potential as said crucible.

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