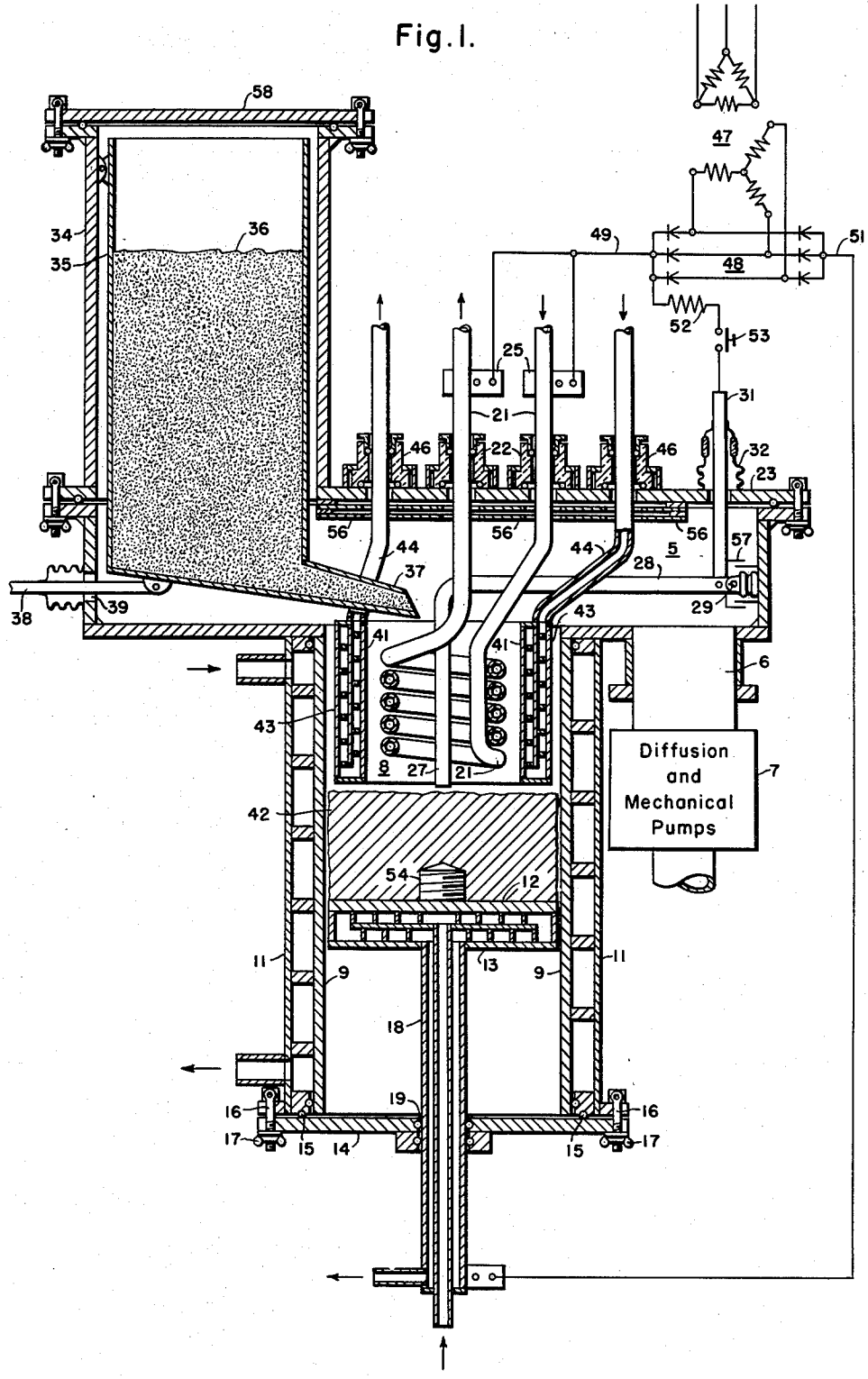
Dec. 20, 1955 J. L. BOYER 2,727,937

HIGH-VACUUM TITANIUM FURNACE

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Fig. 1.

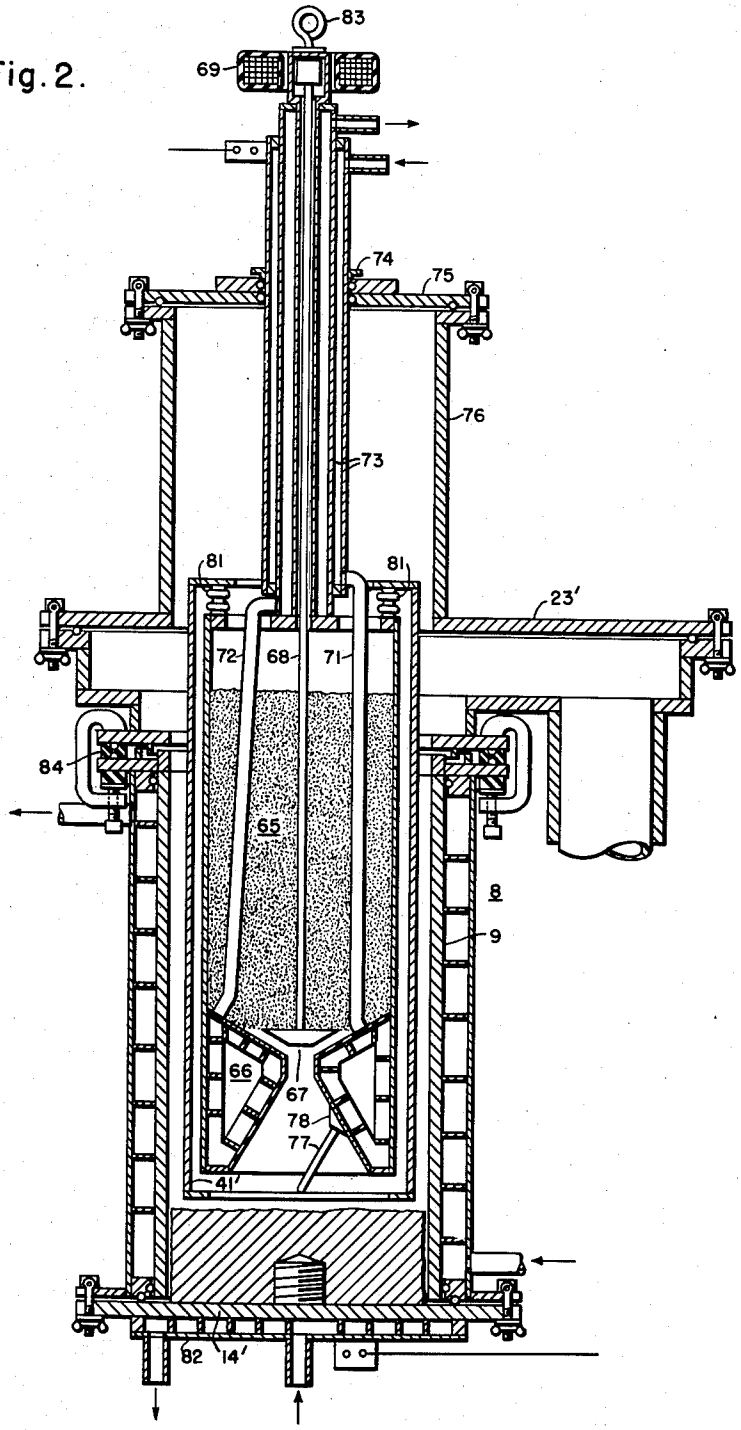


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HIGH-VACUUM TITANIUM FURNACE

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Fig. 2.

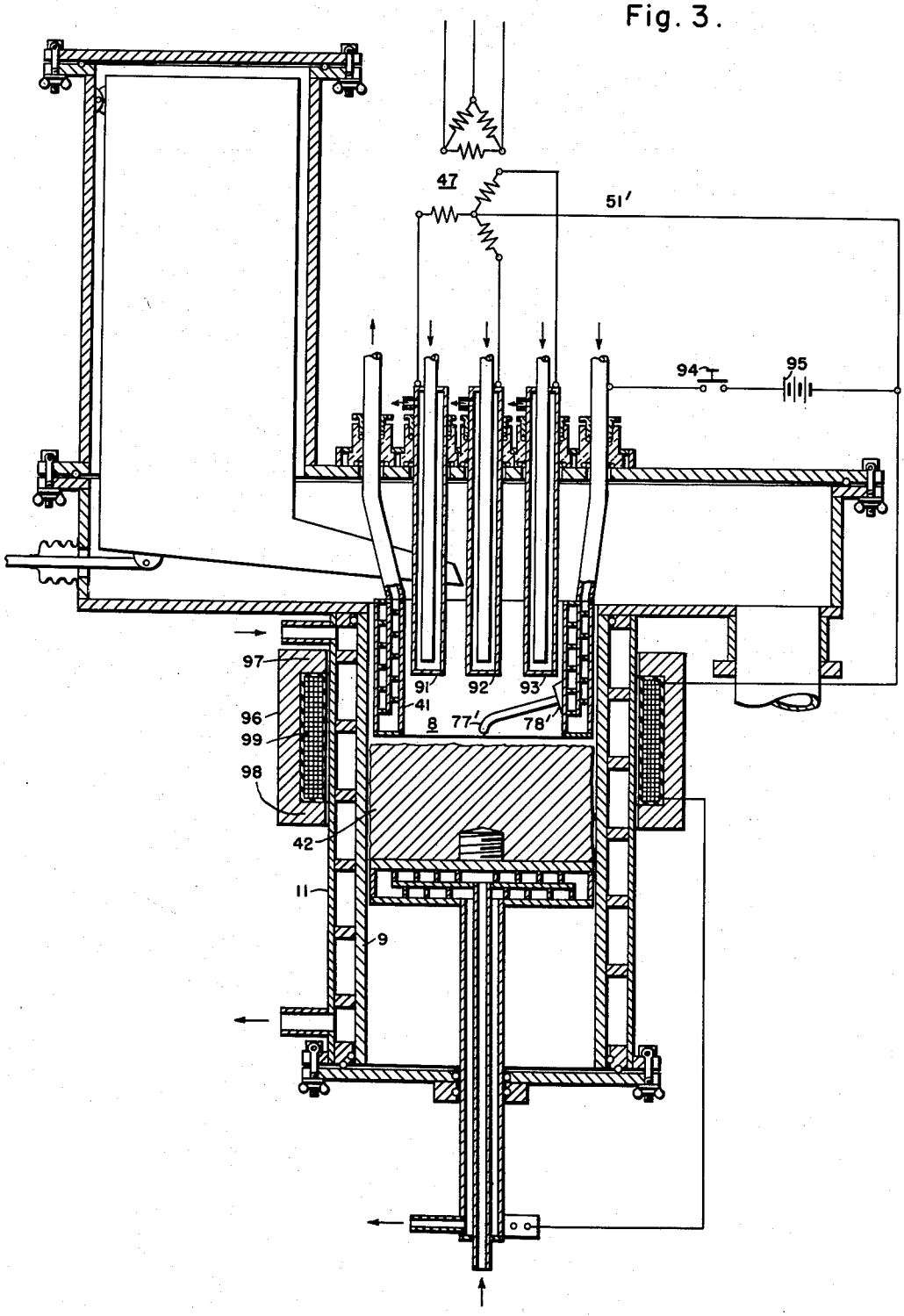


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HIGH-VACUUM TITANIUM FURNACE

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Fig. 3.

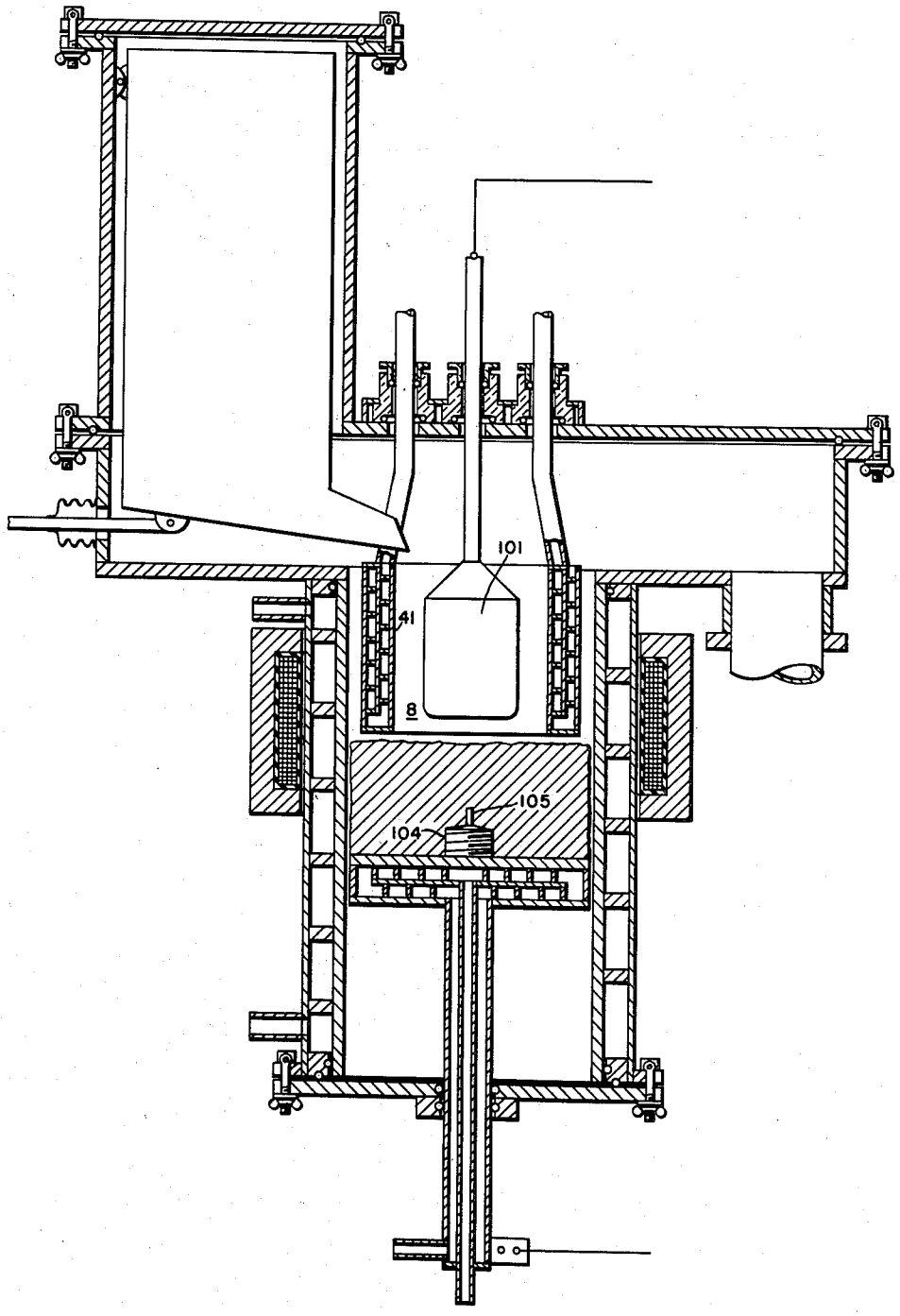


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HIGH-VACUUM TITANIUM FURNACE

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Fig. 4.



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2,727,937

HIGH-VACUUM TITANIUM FURNACE

John L. Boyer, Pittsburgh, Pa., assignor to Westinghouse Electric Corporation, East Pittsburgh, Pa., a corporation of Pennsylvania

Application May 26, 1954, Serial No. 432,371

13 Claims. (Cl. 13—33)

My invention relates to an electric-arc furnace for titanium or other high-melting-point metal. While not limited to any precise size or condition of the metal to be melted, my invention is especially adapted to the arc-melting of high-melting point, electrically conducting, particulate material composed of any-sized small particles which are substantially smaller than the size of the ingot or casting or melt which is to be produced or formed in the furnace. I especially contemplate the melting of a material, such as titanium, which is air-sensitive or oxygen-hungry or otherwise chemically active at its melting temperature, or the melting of metals such as titanium, zirconium, chromium, molybdenum and tungsten, as well as the carbides, oxides and other compounds of such metals, which have a melting point so high as to involve contamination-difficulties with ceramics and conventional crucible-materials. In general, the melting-pot or crucible or mold will be made from a fluid-cooled material, such as copper, which is a good heat-conductor, so that the molten titanium will not be in contact with a hot crucible of any available crucible-material, thus avoiding the destruction of the crucible and the contamination of the titanium.

There have been two general types of electric-arc melting-furnaces for titanium, in the past. One type used a small anode or cathode for the arc, said anode or cathode being disposed above the melt and being composed of graphite or a metal having a still higher melting point than the melt, in combination with means for pouring in the powdered material which is to be melted. The furnace operated at atmospheric pressure or other sufficiently high pressure so that the arc did not spread over a large area of the electrodes. This type of furnace had the disadvantage that enough of the anode-material would become vaporized, to objectionably contaminate the melt.

The other, and more practical, previously known form of electric-arc melting-furnace required the use of a long anode or cathode of compressed sponge-titanium, which was melted off into a pool of molten titanium which was held in a water-cooled copper mold. The titanium electrode was made up from a sponge form of titanium which was obtained in the form of small pieces or blocks, which had been compressed until they were about 75% solid. These blocks had to be carefully welded together in order to produce an anode containing sufficient titanium to produce a melt which is considerably larger than any one of the available compressed blocks of sponge-titanium. Such a furnace operated at sufficient gas pressure to keep a concentrated arc. This type of furnace had the disadvantages that considerable cost was required to produce the pressed titanium-sponge anode, and that the furnace could not be operated at low gaseous pressures because the cathode spot of the arc would then spread over to, and burn, the water-cooled wall of the cathodic container, or if the potential was reversed, the cathode-spots would run up the sides of the titanium-sponge electrode and not melt the end of the electrode. Since a high vacuum could not be used, the titanium had

to be melted, therefore, in a protective atmosphere, usually consisting of a mixture of helium and argon.

My present invention overcomes such disadvantages by using an anode which has a large effective area which is cooled to a point such that the anode is substantially non-consuming, the titanium being introduced in the powdered or crushed form. I use a vacuum which is high enough, or a pressure which is low enough, so that the arc spreads out and covers a large area of anode, thus making it feasible to use an anode which has a sufficiently large effective surface-area so that it is possible to adequately cool it to such a point that substantially no impurities are introduced into the melt from the anode-material. The cathode spots are held on the molten titanium surface, even at very low pressures, by means of special shielding or special magnetic fields.

If the anode of my improved furnace is composed of a large mass of titanium, its cooling can be effected by radiation to other fluid-cooled surfaces in the furnace, to such a degree that the anode is not melted or consumed at any substantial rate; and such trace-quantities of the anode-material as may get into the melt will not be objectionable because the anode is composed of substantially the same material as the melt.

On the other hand, the anode of my furnace can be directly water-cooled, in which case, it would not be made of titanium, and would not need even to be made of a high-melting-point metal. In fact, I prefer to use water-cooled anodes of copper, or other good conductors of heat and electricity, which are cooled to such a point that no objectionable quantities of impurities are introduced into the melt by reason of the vaporization of the anode-material.

In order to make possible the use of such a good vacuum, in all forms of embodiment of my invention, the furnace must be provided with a means for shielding the wall of the container, or otherwise protecting it, so that the arc will not spread out and play upon the wall of the container. For this purpose, I may use either a shield, or a magnetic field, or both, as will be subsequently described.

Several exemplary forms of embodiment of my invention are shown in the accompanying drawing, wherein:

Figure 1 is a diagrammatic view of circuits and apparatus, using my invention in an exemplary direct-current furnace using a single water-cooled main anode, the furnace-structure being indicated by means of a somewhat diagrammatic vertical sectional view;

Fig. 2 is a somewhat diagrammatic vertical sectional view of a modified form of embodiment of the type of furnace which is shown in Fig. 1, with a different location of the hopper for the powdered titanium, and with a different means for maintaining the desired arc-length;

Fig. 3 is a diagrammatic view of circuits and apparatus, using my invention in a three-phase arc-furnace which serves as its own rectifier, with a somewhat diagrammatic representation of a vertical sectional view of the furnace, said furnace being also provided with a magnetic field for assisting in keeping the arc off of the side-walls of the melting-pot; and

Fig. 4 is a view similar to Fig. 1, showing an alternative construction, using a substantially non-consuming titanium anode, as well as the means for producing the magnetic field as shown in Fig. 3.

In Fig. 1, I show my invention as being embodied in an electric-arc melting furnace which comprises an air-tight enclosure 5, which is provided with a pumping connection 6 whereby the enclosure may be evacuated, as by means of diagrammatically indicated diffusion and mechanical pumps 7. A lower portion of the enclosure consists of a nonconsuming cathodic melting-pot 8, which

consists of cylindrical copper side-walls 9 which are surrounded by a water-jacket 11 for cooling purposes, and a removable or plunger-type copper bottom-wall 12 which is cooled by a water-jacket 13 disposed beneath said bottom-wall. The inner surfaces of the side and bottom walls 9 and 12 of the melting-pot 8 are thus disposed within the enclosure 5.

Underneath the bottom-wall 12 of the melting-pot or crucible or mold 8, the air-tight enclosure 5 is provided with a removable bottom-plate 14, which is provided with an air-tight gasket 15, and which is held in place by hinged bolts 16 having quickly removable wing-nuts 17. The bottom-wall 12 of the melting-pot 8 is provided with a depending piston-rod or supporting column 18, which passes slidably through a suitably gasketed perforation 19 in the center of the bottom-plate 14 of the enclosure. The lower end of the piston-rod or supporting-column 18 is provided with a supporting-means (not shown), which is usually in the form of a lifting-jack which is provided whereby the melting-pot bottom-wall 12 may be raised or lowered, as is well understood in the art.

In the upper portion of the melting-pot 8, in Fig. 1, I provide an annular water- or fluid-cooled main anode 21, which is shown in the form of a coil or cylindrical helix of metal tubing which may be made of copper or other good conductor of heat and electricity. The inlet and outlet ends of this copper tubing 21 extend up through suitable insulating air-tight bushings 22 which are provided in a removable top-plate 23 of the enclosure 5, so that cooling-water may be admitted to, and discharged from, this anode-coil 21, as diagrammatically indicated by the arrows, and so that electrical connections may be made, as indicated at 25.

Disposed centrally inside of the anode-coil 21 is a small starting-anode 27, which is preferably made of titanium, and which merges with, or is connected at its top to, a horizontal supporting-portion 28, the end of which is insulatedly pivoted, at 29, to a side wall of the enclosure 5. This horizontal supporting-portion 28 of the starting-anode 27 can be raised or lowered, as by means of a starting-anode terminal-lead 31, which is insulatedly connected to an air-tight bellows 32 surrounding a hole in the removable top-plate 23 of the enclosure 5.

The top-plate 23 of the enclosure in Fig. 1 is illustrated as being provided with an upwardly extending cylindrical extension 34, which serves as a housing for a hopper 35 which is adapted to contain the powdered material, such as titanium 36, which is to be melted into an ingot which is formed in the melting-pot or mold 8. The lower end of the hopper 35 is provided with a funnel 37, or other suitable means, whereby the powdered material may be delivered so that it will drop down through the anode-coil 21 during the operation of the furnace. Any suitable powder-delivering control-mechanism may be used, such as is symbolically indicated by an operating-means which is secured to the bottom of the hopper 35, said means being illustrated as a horizontal shaker-rod 38, which extends through a bellows-surrounded hole 39 in a side wall of the enclosure 5.

In accordance with my invention, the annular space between the anode-coil 21 and the upper portions of the side-walls 9 of the melting-pot 8, is occupied by a cylindrical arc-shield or baffle 41, for preventing, or helping to prevent, the arc from playing over onto the side-walls 9 of the melting-pot. Preferably, the lower end of the baffle 41 extends slightly lower than the lower end of the anode 21, but not low enough to come into contact with the top of the melt or ingot 42 which is being produced in the melting-pot. In many cases, some or all of the baffle will be water-cooled, as by means of a water jacket 43, terminating in pipes 44 which extend through insulating air-tight bushings 46 in the top-plate 23 of the enclosure.

Electrical energy is applied to the furnace of Fig. 1

through a step-down delta-star transformer 47, which feeds low-voltage high-current energy of something like 2,000 amperes or more, through rectifiers 48 having an anode lead 49 which is connected to the electrical connections 25 of the main anode 21, and a cathode-lead 51 which is connected to the supporting-stem 18 of the bottom-wall 12 of the melting-pot 8. A branch-connection is also provided, from the anode-lead 49, through a starting-anode resistor 52 and a switch or push-button 53, to the starting-anode terminal-lead 31.

In the operation of the apparatus shown in Fig. 1, the bottom-wall 12 of the melting-pot 18 is initially in its uppermost position. Preferably, this bottom-wall 12 initially carries, at its center, a small starting-electrode or base 54 of titanium, which can be momentarily engaged by the bottom tip of the starting-anode 27, which is quickly drawn away, either by a slight lowering of the bottom-wall 12, or preferably by a quick elevation of the starting-anode 27, through an upward pull on its terminal-lead 31. If the starting-anode 27 is raised high enough, it will not appreciably melt, and may be used for many successive melting or molding operations of the furnace. Whether the initial titanium starting-cathode lump 54 is used or not, it is also desirable initially to pour in some powdered titanium from the hopper 35, before the starting-switch or push-button 53 is closed.

As soon as the starting-arc is formed at the bottom of the starting-anode 27, a main arc forms, between the main anode 21 and the small amount of titanium material which is initially carried by the bottom-wall 12 of the melting-pot 8. Sufficient current must be fed into the main anode 21 to melt the powdered titanium as it is fed into the melting-pot 8 from the hopper 35, this operation usually requiring more than 2,000 amperes, or whatever amperage may be necessary, depending upon the size of the apparatus and the rate at which the melting-operation is to be accomplished.

Because of the maintenance of a high vacuum, through the pumping connection 6, the arc, or a multitude of small parallel-operating arcs, spread out and cover a large area of the anode 21, as well as a fairly large area in the central portion of the top of the material in the melting-pot 8. Usually, this will require a pressure of less than several millimeters of mercury, say 5 millimeters or less, or in general a pressure at which the arc thus spreads out and covers a large area of anode. Because of the large anode-area, it is possible, in my furnace, to successfully water-cool the anode, so that its large effective surface is kept so cool that it will not be objectionably vaporized by the playing of the ever-moving arc-terminals thereon, thus avoiding both the destruction of the anode and the contamination of the titanium-melt or ingot, as well as avoiding the necessity for using a high-melting-point non-consuming anode-material.

The arc-shield or baffle 41 prevents the cathode spots from moving over onto the furnace-wall 9. This is accomplished by causing the bottom of the shield or baffle 41 to be spaced by only a small distance from the top of the molten material or melt 42 in the melting-pot 8, so that the arc-length of any arc which would terminate on the side-walls 9, above this melt or ingot 42, would cause such an arc to have an arcing-voltage which is higher than the arcing voltage of the shorter main-arcs which play, in a more direct path, between the anode 21 and the melt or ingot 42, so that the longer arcs, such as an arc which has a cathode-spot on the side-walls 9, could neither form itself in the first place, nor be maintained if for an instant it might be formed for any reason. The position of the plunger-type bottom-wall 12 of the container or melting-pot 8 must be such that only a small gap is maintained between the bottom of the shield or baffle 41 and the surface of the molten titanium ingot or melt 42. Only the top surface of this titanium ingot is melted, and the part below it forms a solid ingot of titanium. There will be many cathode spots on the sur-

face of the titanium, so that it will remain molten, but the copper wall 9 of the container will not be melted, because of its water-jacket 11, and because the space between the bottom of the shield 41 and the surface of the titanium is too restricted to maintain an arc which extends over to the side-walls 9, as just explained.

I have not attempted to illustrate a means for determining the level of titanium from the outside of the furnace, as suitable means for this purpose can be provided, either by means of measuring the wall-temperature, or by measuring the voltage of the arc-drop within the furnace. My present invention does not concern itself with such details, other than that suitable means should be provided.

The heat which is radiated from the molten titanium surface is shielded from the main bushings 22 and 46 by heat-shields 56, which also prevent evaporated titanium from condensing on the insulators. The insulated pivotal joint 29 for the starting-anode 27 may also be shielded, as indicated at 57, for preventing condensation on this insulator.

When the melting operation is ended, the finished ingot 42 is removed by loosening the removable bottom-plate 14 of the enclosure, and lowering the piston-type bottom-wall 12 of the melting-pot or mold 8. After the removal of the ingot, the piston-type bottom-wall 12 may be replaced in the mold or melting-pot 8, and the bottom-plate 14 of the enclosure may be bolted back in place.

Before the furnace is ready for a second melting-operation, it is usually necessary to replenish the powdered titanium in the hopper 35, which may be accomplished by means of a readily removable hopper-cover 58, which closes the top of the hopper-housing 34.

Fig. 2 shows a modified form of my furnace in which, instead of using the hopper 35 of Fig. 1, I provide a hopper 65 which is disposed above the water-cooled annular anode 66. This hopper 65 is provided, at its lower end, with a valve or gate 67, for dropping powdered titanium (or other particulate material) through the annular anode 66, under the control of an upwardly extending valve-stem 68, which is operated, at the top, by means of an external solenoid or magnet-coil 69.

In Fig. 2, the water-cooled annular anode 66 is in the form of a double-walled funnel-shaped device, with the space between the two walls occupied by a spiral or other baffling-means for causing the cooling-water, which enters through the inlet-pipe 71, to travel through the anode and be expelled through the outlet-pipe 72. The inlet and outlet-pipes 71 and 72 are in communication with nested cylinders 73 which are vertically slidable within a suitable air-tight gland 74 in the remarkable cover 75 of an upstanding cylindrical wall-member 76 which extends up from the top-plate 23'.

In Fig. 2, the movable starting-electrode 27 of Fig. 1 is omitted, and its place is taken by a small replaceable consumable titanium starting-anode 77, which is frictionally inserted in a protuberance 78 on the inner funnel-surface of the main anode 66. This starting-anode 77 melts away and disappears, in the heat of the main arc, after said starting-anode has completed its starting-function in Fig. 2.

In Fig. 2, the baffle or arc-shield 41' is not directly water-cooled, being cooled by its juxtaposition to the cooled anode 66 and the cooled side-walls 9 of the melting-pot 8. This baffle or arc-shield 41' is supported, at its top, by insulators 81 which rest on top of the hopper 65 in Fig. 2.

A further alternative construction, which is shown in Fig. 2, concerns the method by which a proper arc-length is maintained within the furnace. Instead of using the system shown in Fig. 1, in which the arc-level is always at the same point, being determined by the position of the bottom end of a fixed main anode 21, the arc-level in Fig. 2 is at variable heights, starting at or near the bottom of the melting-pot 8, and mounting upwardly as the molten titanium is deposited in said melting-pot. Thus, in Fig. 2, instead of providing a movable water-cooled bottom-wall 12 for the melting-pot 8, as shown in Fig. 1, this element is omitted in Fig. 2, and its place is taken by the central portion of the bottom-plate 14' of the entire enclosure, this central portion of the bottom-plate being cooled, as indicated by the water-jacket 82. In order to maintain the proper arc-length, the entire anode-assembly is gradually raised, during the operation of the furnace of Fig. 2, so as to maintain a constant arc-length, or a constant separation of the main anode 66 and the baffle or arc-shield 41' above the molten surface of the titanium melt in the melting-pot 8. The raising of the anode-structure in Fig. 2 can be accomplished, at the extreme top of the anode-assembly, by the use of a suitable lifting-bolt 83, which may be mechanically lifted, under either manual or automatic control, as may be needed in order to maintain the proper arc-length or arc-voltage.

In Fig. 2, also, I provide a structure in which, instead of requiring insulating bushings 22 and 46, in a top-plate 23 which is electrically at the same potential as the cathodic melting-pot 8, I provide a main cylindrical or annular insulator 84, which provides electrical insulation between the melting-pot 8 of Fig. 2 and the top-plate 23' thereof, so that the nested cylinders 73 do not need to be insulated from the removable cover 75 of Fig. 2, at the place where they slide through their air-tight gland 74.

It is believed that the operation of the apparatus shown in Fig. 2 will be readily understandable from the explanations which have been given in the course of its description, and from the explanation of the operation of the apparatus shown in Fig. 1.

Fig. 3 shows two other features of my invention, which could be embodied in any of the forms of embodiment of the invention; namely, a polyanode construction, and a magnetic shielding-means for keeping the arc off of the side-walls 9 of the melting-pot 8. Thus, in Fig. 3, the furnace is provided with three water-cooled anodes 91, 92 and 93, which, for diagrammatic purposes, have been shown all in a straight line, although it will be readily understood that they will actually be deposed at the apices of an equilateral triangle, that is, symmetrically with respect to the center-line of the melting-pot. The furnace-structure may otherwise be similar, in most respects, to that which has been described in connection with Fig. 1, except that, in Fig. 3, the three anodes 91, 92 and 93 are directly energized from the three secondary phase-terminals of the main power-transformer 47. These three anodes operate as a three-phase rectifier, so that a direct current flows to the cathode-pool or top-surface of the melt or ingot 42. The cathode lead 51', in Fig. 3, is connected to the star-point of the secondary winding of transformer 47.

In Fig. 3, instead of using a movable starting-anode 27 such as was shown in Fig. 1, I have shown a small replaceable consumable titanium starting-anode 77', similar to that which was shown in Fig. 2, this starting-anode 77' being frictionally held, in Fig. 3, within a protuberance 78' which is carried by the inner cylindrical surface of the cylindrical baffle or shield 41 which surrounds the three anodes 91, 92 and 93. The small needed starting-current for the starting-anode 77' may be provided, in Fig. 3, by a starting-circuit containing a switch or push-button 94 and a battery 95, connected between one of the cooling-pipes for the baffle 41, and the cathode-lead 51' or the secondary star-point of the transformer 47. This small titanium starting-anode 77', in Fig. 3, melts off, in the heat of the main arc, during the first few moments of operation of the furnace.

In Fig. 3, I also show the use of a magnet-means which is disposed outside of the side-walls of the melting-pot 8, and an internal magnetic cylinder which is water cooled, for producing a magnetic field having flux-lines which leave or enter the top surface of the melt 42 in a

ring-shaped area within the melting-pot. In Fig. 3, this external magnet-means is shown in the form of an annular magnetizable ring or core **96**, having a channel-shaped cross-section, so that it terminates in upper and lower flanges or pole-pieces **97** and **98**, which come close to the main water-jacket **11** which surrounds the side-walls **9** of the melting-pot **8**, the upper pole **97** being above the level of the top surface of the titanium ingot **42**, while the lower pole **98** is below said surface. Any suitable means may be used for giving this magnet-member **96** the properties of either a permanent or electric magnet, so that its upper pole **97** will be of one polarity, while its lower pole **98** is of the opposite polarity, the direction of the polarity being immaterial. An electrically energized magnetizing means is shown, in the form of a direct-current coil **99**, which is disposed either inside or outside of the vertical portion of the magnet **96**. In the illustrated embodiment, the coil **99** is disposed inside of the magnet **96**, between the upper and lower flanges **97** and **98**, and it is serially connected in the cathode-lead **51'**.

To make the magnet-means of Fig. 3 effective, it is necessary that the side-walls **9** of the melting-pot **8**, as well as the metal parts of the water-jacket **11**, shall be of non-magnetizable material, so that the magnetic flux which enters and leaves the inner peripheries of the upper and lower flanges **97** and **98** shall be able to penetrate into the space within the melting-pot **8**. The baffle or arc-shield **41** (if it is used at all) may be of either non-magnetizable or magnetizable material. If said shield **41** is used, as illustrated in Fig. 3, it is advantageous to make it of magnetizable material, so that a good share of the flux of the magnet-member **96** will flow in a vertical direction in this shield **41**. The lower end of this shield then acts as an annular magnet pole which is spaced closely above the top surface of the titanium melt **42**, at a radius which is just inside of the outer rim of the top surface of this melt or ingot.

The magnetic lines of force, in Fig. 3, are thus disposed in an essentially vertical direction, or a direction having a vertical component, so that any arc which might tend to drift over and fasten its cathode-spot onto the side-walls **9** of the melting-pot **8** would have to cut this vertical magnetic field, which would have the effect of swiftly rotating the electrons and ionized particles which compose the arc, thus enormously increasing the effective arc-length, and hence the arc-voltage of such an arc, making it impossible to form such an arc in the first place, or to maintain it even though if, for some inexplicable reason, it might momentarily form with a cathode-spot on the crucible-wall **9**. This long-arc protective action of the magnetic field in Fig. 3 is thus similar to that which has been explained for the baffle or shield **41**, in connection with Fig. 1.

It will be understood, of course, that the magnet-means **96** of Fig. 3 can be used, also, with a single-anode furnace which is supplied with direct current. It will also be understood that the single water-cooled copper non-consuming anode **21** of Fig. 1 could be replaced with a solid or massive anode which is made of titanium or compressed titanium sponge, and which, because of its mass and its large surface-area, and its juxtaposition to other members which are water-cooled, operates at a low enough temperature so that the titanium of the anode is not melted or consumed or any material extent. These alternative structures are illustrated in Fig. 4.

In Fig. 4, the main anode **101** is an uncooled solid block of titanium, or piece of compressed titanium sponge, or other material which is substantially the same as the substance of which the melt or ingot **42** is to be composed. This anode is too big, and too close to adjacent cooled surfaces, to get hot enough to melt, but it runs fairly hot, much hotter than the water-cooled copper anode **21** of Fig. 1. The advantage of a hot anode is that it prevents the condensation of such slight impurities as may be present in the furnace, so that these impurities do not condense on the anode, where they might interfere with the functioning of the anode as a suitable arc-terminal, particularly if said impurities were non-conducting. Nevertheless, since the anode **101** runs fairly hot, there will be more vaporization because of its fairly high temperature, but by making the anode of titanium, I prevent any slight vaporization of the anode-material from introducing impurities in the melt, which is also of titanium.

The Fig. 4 construction uses the same hopper arrangement as in Fig. 1, for pouring powdered titanium down between the anode **101** and the baffle or shield **41**, and thus into the melting-pot **8** of the furnace.

Fig. 4 illustrates the use of a slightly different type of starting-electrode, in which the starting-cathode mass **54** of Fig. 1 is replaced by a starting-cathode mass **104** which is provided with a small upstanding spike **105**, which serves as a small consumable titanium starting-electrode, which will be melted in the first few moments of operation of the device.

My new furnaces have the advantage that very large ingots can be made from a powdered titanium source, without having to compact the sponge-titanium material and weld it together to form a consumable electrode. By using a high vacuum in the furnace, good titanium can be produced, with only one melting, since the time in the melting stage can be controlled by the rate at which new material is added to the melt. My furnaces were more particularly designed for ingots larger than 12 inches in diameter, but the furnaces could be made in almost any size.

I would emphasize the importance of the internal shield as a means for making possible the use of a low-pressure non-concentrated arc, and the importance of the small space which is required, between the bottom of this shield and the melt, in order to keep the low-pressure arc off of the side-walls.

While I have illustrated only a few suggestive forms of embodiment, and while I have described my furnaces more particularly with reference to the melting of titanium, I wish it to be understood that my invention is not limited to these precise structural forms or to the use of only titanium as the composition of the melt or ingot. Certain structural features which are not specifically claimed herein are claimed in a companion-application of Edwin W. Johnson, Serial No. 479,881, filed January 5, 1955.

I claim as my invention:

1. An electric-arc furnace for particulate material consisting of a high-melting-point electrically conducting substance which is chemically active at its melting temperature, said furnace comprising a substantially air-tight enclosure, a nonconsuming cathodic melting-pot comprising fluid-cooled side-walls and a fluid-cooled bottom-wall having inner surfaces which are within a lower portion of said enclosure, said side-walls and said bottom-wall being made of a metal which is a sufficiently good heat-conductor so that their inner surfaces are kept below the temperature at which a substantial reaction takes place with a melt in the melting-pot, said bottom-wall being removable from the enclosure whereby a melt may be removed from the melting-pot, nonconsuming anode-means having an extensive active surface-area which is within the enclosure and which is within the side-walls of said melting-pot in spaced relation thereto, a hopper for said particulate material in an upper portion of said enclosure, said enclosure further having a removable portion whereby a fresh charge of particulate material may be introduced into said hopper, a means for discharging particulate material from said hopper into said melting-pot, terminal-means whereby an electric arc may be caused to play between said anode-means and the top of a melt which is accumulating in said melting-pot, a means for maintaining, in said enclosure, a vacuum which

is high enough to cause the arc to spread out and cover a large area of both the anode-means and the melt, the material to be melted being of such nature as to be susceptible to such arc-spreading over the top of the melt at the operating vacuum, a means, which is out of contact with the molten top surface of the melt, for keeping the arc from moving over the top surface of the melt to the side-walls of the melting-pot, and a vertical-adjustment means whereby to adjust the arc-length between said anode-means and the melt in said melting-pot.

2. The invention as defined in claim 1, characterized by said anode-means being operated under such conditions that its surface-temperature remains sufficiently low to substantially prevent the melting of the electrode-material and the contamination of the melt, during the operation of the furnace, further characterized by the side-walls of said melting-pot being of non-magnetizable material, and still further characterized by said means for keeping an arc-terminal from moving over to said side-walls comprising a magnet-means disposed outside of said side-walls for producing a magnetic field having flux-lines which leave or enter the top surface of the melt within said melting-pot.

3. The invention as defined in claim 1, characterized by said anode-means being operated under such conditions that its surface-temperature remains sufficiently low to substantially prevent the melting of the electrode-material and the contamination of the melt, during the operation of the furnace, and further characterized by said means for keeping an arc-terminal from moving over to said side-walls comprising a nonconsuming shielding-means disposed between said anode-means and said side-walls the lower end of said shielding-means being spaced closely above the top of the melt, and further characterized by said vertical-adjustment means including a means whereby to adjust the spacing between the lower end of the shielding-means and the top of the melt.

4. The invention as defined in claim 3, characterized by at least a portion of said shielding-means being fluid-cooled.

5. The invention as defined in claim 3, characterized by the lower end of said shielding-means extending below the lowest surface of said anode-means, in combination with a consumable starting-electrode whereby an arc may be started between said starting-anode and said cathodic member without ever bringing said shielding-member into electrical contact with said cathodic member.

6. The invention as defined in claim 3, characterized by the side-walls of said melting-pot being of non-magnetizable material, and further characterized by said means for keeping an arc-terminal from moving over to said side-walls further comprising a magnet-means disposed outside of said side-walls for producing a magnetic field having flux-lines which leave or enter the top surface of the melt within said melting-pot.

7. The invention as defined in claim 3, characterized by the side-walls of said melting-pot being of non-magnetizable material, further characterized by said shielding-means being of magnetizable material, and still further characterized by said means for keeping an arc-terminal from moving over to said side-walls further comprising a magnet-means disposed outside of said side-walls for producing a magnetic field between the lower end of the shielding-means and the rim-portion of the melt in said melting-pot.

8. An electric-arc furnace for particulate material consisting of a high-melting-point electrically conducting substance which is chemically active at its melting temperature, said furnace comprising a substantially air-tight enclosure, a nonconsuming cathodic melting-pot comprising fluid-cooled side-walls and a fluid-cooled bottom-wall having inner surfaces which are within a lower portion of said enclosure, said side-walls and said bottom-wall being made of a metal which is a sufficiently good heat-conductor so that their inner surfaces are kept below the temperature at which a substantial reaction takes place with a melt in the melting-pot, said bottom-wall being removable from the enclosure whereby a melt may be removed from the melting-pot, an anode of substantially the same substance as the particulate material which the furnace is adapted to melt, said anode having an extensive active surface-area which is within the enclosure and which is within the side-walls of said melting-pot in spaced relation thereto, a hopper for said high-melting-point, electrically conducting, particulate material in an upper portion of said enclosure, said enclosure further having a removable portion whereby a fresh charge of particulate material may be introduced into said hopper, a means for discharging particulate material from said hopper into said melting-pot, terminal-means whereby an electric arc may be caused to play between said anode and the top of a melt which is accumulating in said melting-pot, a means for maintaining, in said enclosure, a vacuum which is high enough to cause the arc to spread out and cover a large area of both the anode and the melt, the material to be melted being of such nature as to be susceptible to such arc-spreading over the top of the melt at the operating vacuum, a fluid-cooled non-consuming shielding-means, disposed between said anode and said side-walls, the lower end of said shielding-means being spaced closely above the top of the melt whereby to keep the arc from moving over the top surface of the melt to the side-walls of the melting-pot, and a means whereby to adjust the arc-length between said anode-means and the melt in said melting-pot, and whereby to adjust the spacing between the lower end of the shielding-means and the top of the melt, said anode having such a size and thermal relation to other cooled surfaces that it does not get hot enough to melt in substantial quantities during the operation of the furnace.

9. The invention as defined in claim 8, characterized by the side-walls of said melting-pot being of non-magnetizable material, further characterized by said shielding-means being of magnetizable material, in combination with a magnet-means disposed outside of the side-walls of the melting-pot for producing a magnetic field between the lower end of the shielding-means and the rim-portion of the melt in said melting-pot, for further assisting in keeping an arc-terminal from moving over to the side-walls of the melting-pot.

10. An electric-arc furnace for electrically conducting material which is chemically active at its melting temperature, said furnace comprising a substantially air-tight enclosure, a nonconsuming cathodic melting-pot comprising side-walls and a bottom-wall having inner surfaces which are within a lower portion of said enclosure, anode-means disposed within the enclosure and within the side-walls of said melting-pot in spaced relation thereto, terminal means whereby an electric arc may be caused to play between said anode-means and the top of a melt which is accumulating in said melting-pot, a means for maintaining, in said enclosure, a vacuum which is high enough to cause the arc to spread out and cover a large area of both the anode-means and the melt, the material to be melted being of such nature as to be susceptible to such arc-spreading over the top of the melt at the operating vacuum, and a means, which is out of contact with the molten top surface of the melt, for keeping the arc from moving over the top surface of the melt to the side-walls of the melting-pot, said enclosure having a removable portion for providing access for the removal of the melt from the melting-pot, said enclosure further having a vertical-adjustment means whereby to adjust the arc-length between said anode-means and the melt in said melting-pot.

11. The invention as defined in claim 10, characterized by said means for keeping an arc-terminal from moving over to said side-walls comprising a nonconsuming shielding-means disposed between said anode-means and said side-walls the lower end of said shielding-means being

spaced closely above the top of the melt, and further characterized by said vertical-adjustment means including a means whereby to adjust the spacing between the lower end of the shielding-means and the top of the melt.

12. The invention as defined in claim 10, characterized by the side-walls of said melting-pot being of non-magnetizable material, and further characterized by said means for keeping an arc-terminal from moving over to said side-walls comprising a magnet-means disposed outside of said side-walls for producing a magnetic field having flux-lines which leave or enter the top surface of the melt within said melting-pot.

13. The invention as defined in claim 10, characterized by the side-walls of said melting-pot being of non-magnetizable material, further characterized by said means for keeping an arc-terminal from moving over to said side-walls comprising a nonconsuming shielding-means disposed between said anode-means and said side-walls, said shielding-means being of magnetizable material, and a magnet-means disposed outside of the side-walls of the melting-pot for producing a magnetic field between the lower end of the shielding-means and the rim-portion of the melt in said melting-pot the lower end of said shielding-means being spaced closely above the top of the melt, and further characterized by said vertical-adjustment means including a means whereby to adjust the spacing between the lower end of the shielding-means and the top of the melt.

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