Sept. 11, 1956 C. E. NEWCOMB ET AL 2,762,856

CONSUMABLE ELECTRODE FURNACE AND METHOD OF OPERATION

Filed Nov. 1, 1954

5 Sheets-Sheet 1

Fig. 1.

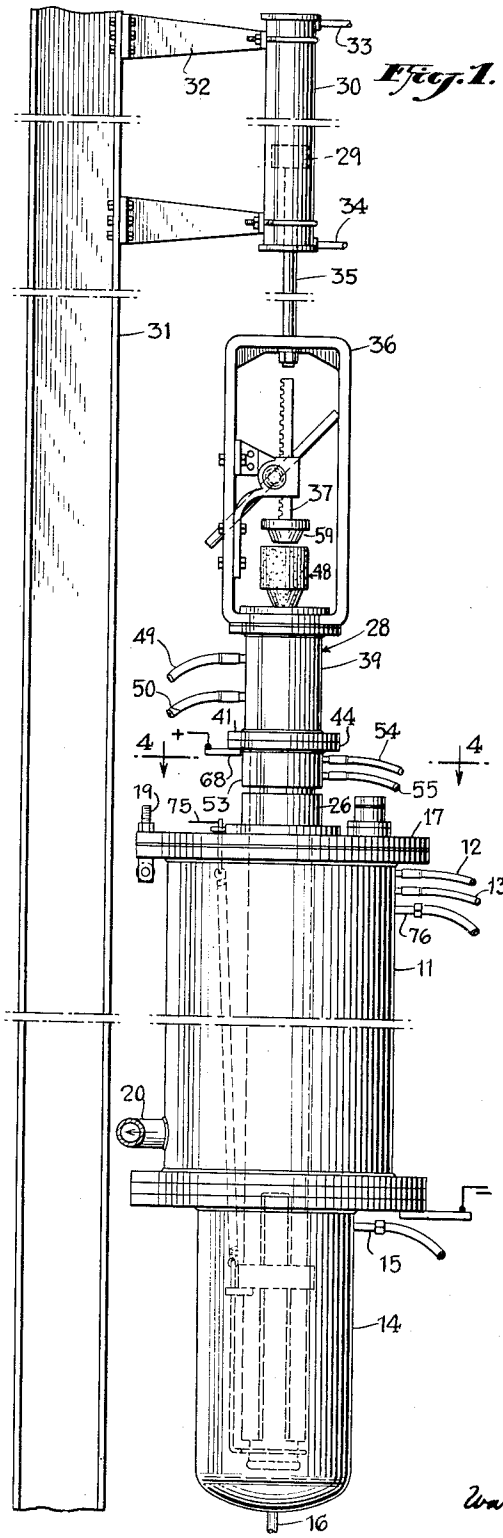


Fig. 4.

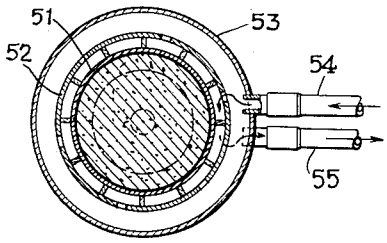
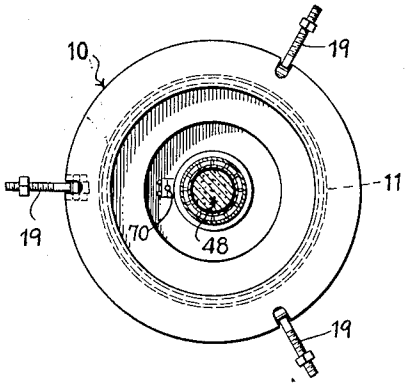


Fig. 8.



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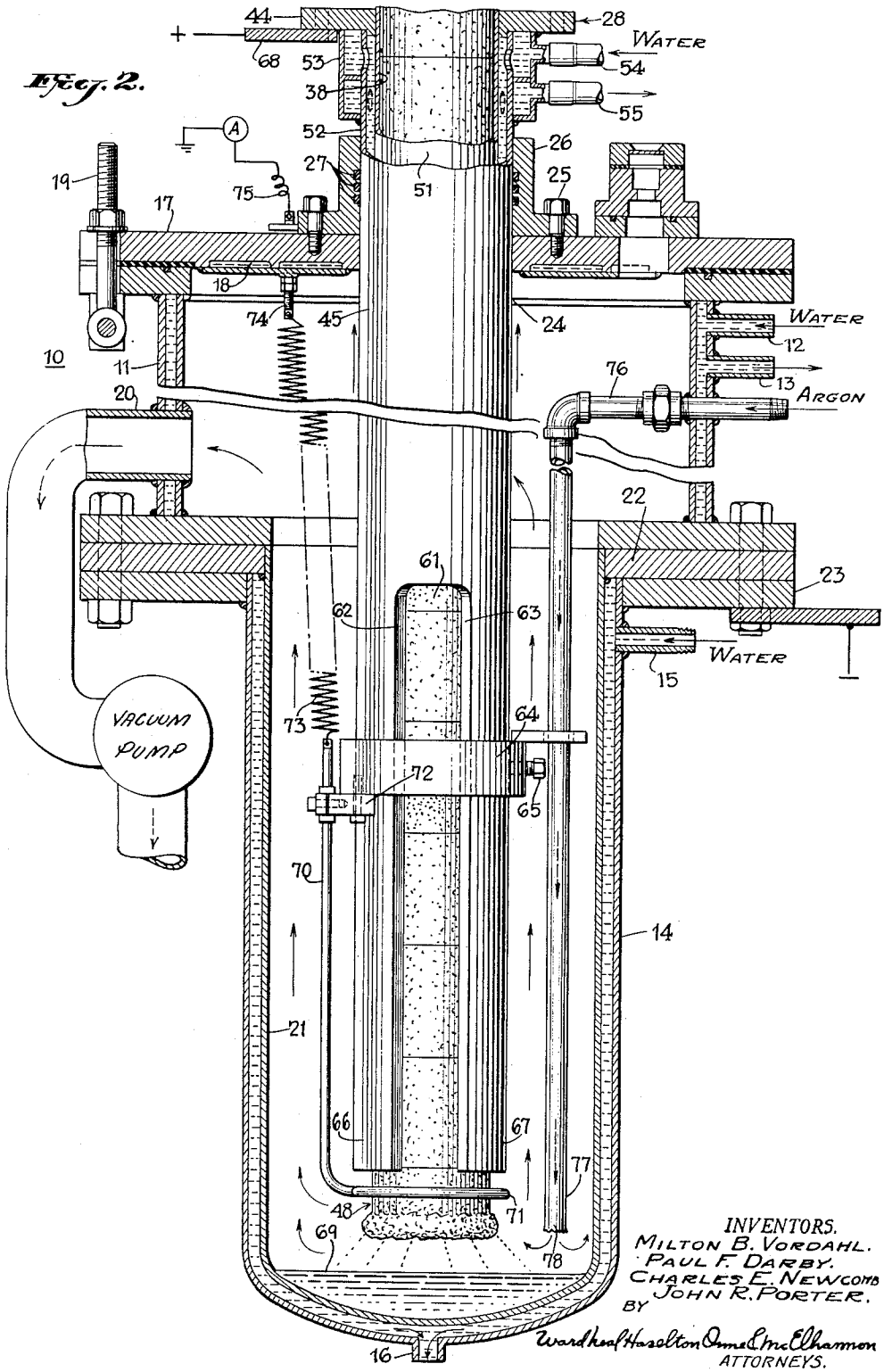
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Fig. 2.



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Fig. 5.

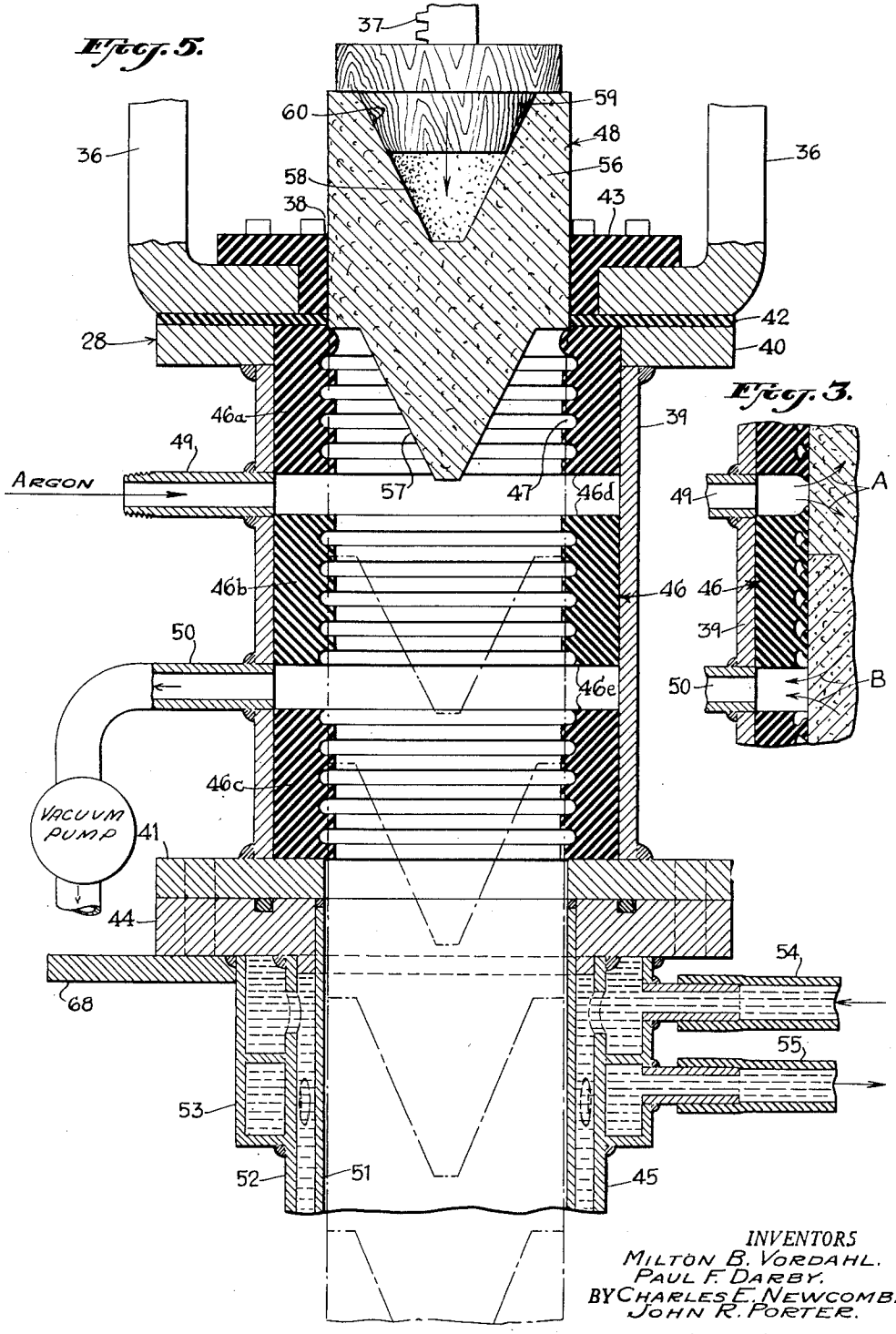


Fig. 3.

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Fig. 6.

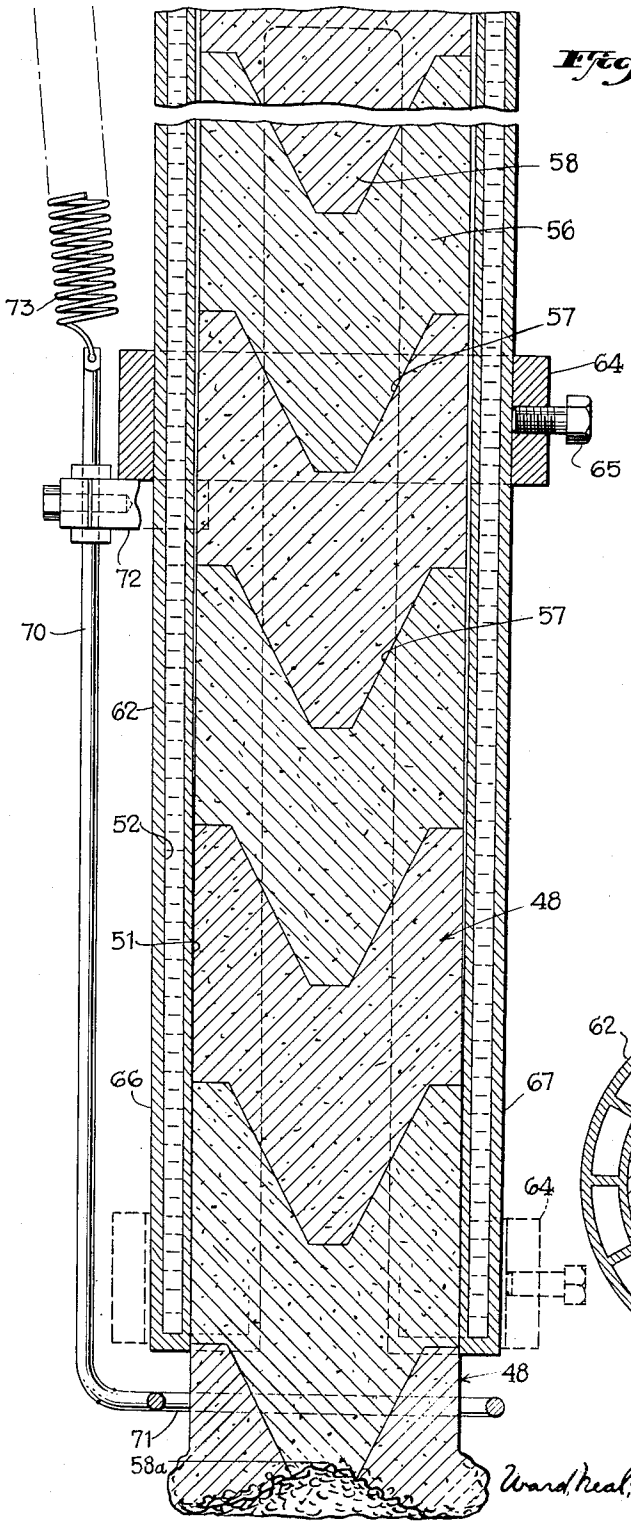
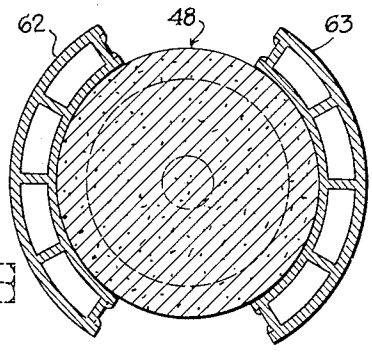


Fig. 7.



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CONSUMABLE ELECTRODE FURNACE AND METHOD OF OPERATION

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Fig. 9.

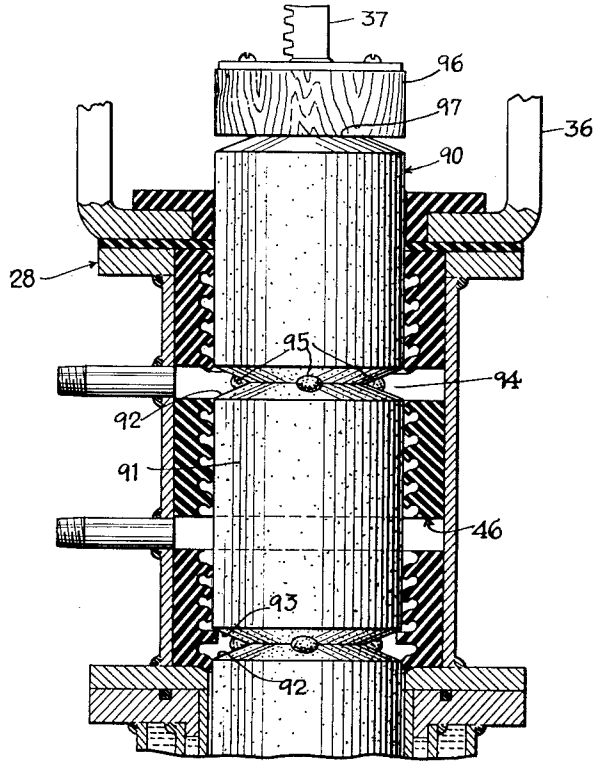
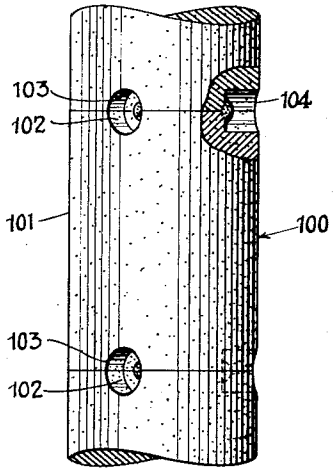


Fig. 10.



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2,762,856

CONSUMABLE ELECTRODE FURNACE AND METHOD OF OPERATION

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Application November 1, 1954, Serial No. 465,944

16 Claims. (Cl. 13—31)

This invention relates to improvements in methods and apparatus for melting and alloying high melting point metals which are highly reactive chemically, such for example, as titanium, zirconium and alloys of each.

Due to the high melting points and high chemical reactivity of metals of the character aforesaid, it has heretofore been common practice to produce ingots thereof by arc-melting the starting materials, in initially comminuted form, in an inert atmosphere, of argon, helium or the like and in a so-called "cold mold" furnace such as a water-cooled copper crucible. This basic procedure has been subject to various modifications and refinements. Originally a tungsten electrode was employed and the comminuted starting material, such for example, as titanium sponge or a mixture of titanium sponge and alloy metal chips, were fed progressively from hoppers through chutes into the crucible, the melting proceeding a little at a time as the ingot is built up in the crucible, due to the chilling or water cooling action of the latter. This procedure is obviously cumbersome and complicated by the apparatus required for feeding in the sponge or sponge and alloy chips, and also by the difficulty in the production of alloys, of feeding the titanium sponge and the alloy chips into the crucible at the proper rates in the appropriate proportions to produce the alloy desired. The ingots thus produced are often contaminated by the tungsten of the electrode, portions of which tend to break off from time to time during the melting.

To eliminate these objections, a later procedure was to replace the tungsten electrode with a consumable electrode composed of pressed compacts of the titanium sponge or sponge and alloy metal chips. Various ways of forming such consumable electrodes have been proposed such, for example, as compacting the comminuted material into substantially cylindrical briquets, welded end to end to produce an elongated electrode, or by rolling the comminuted material into sheets and welding the sheets together into a substantially rectangular cross-section of appropriate sectional dimensions and length, etc. However, consumable electrodes as thus produced are quite frangible and require careful handling to avoid breakage. Also means are required for housing such elongated electrodes in an extension of the furnace housing, extending many feet above the furnace proper, together with means for appropriately feeding the electrode progressively downward toward the arc as the melting proceeds. Further complications are involved in attempting to form the consumable electrodes by means disposed within the furnace housing.

In accordance with the present invention, we propose to overcome the above noted and other objections to the employment of consumable electrode melting as heretofore practiced by means of a novel furnace construction and novel methods and apparatus for feeding consumable electrode briquets thereinto, the outstanding features of which are in substance as follows:

In accordance with our invention, the furnace proper takes the form of an elongated upstanding housing usually

of substantially cylindrical contour. The water-cooled copper crucible is disposed within the housing within the lower portion thereof. The upper portion of the housing is provided with a removable cover, through which slidably extends from the exterior to the interior of the housing, a tubular electrode receptor which is lined at its upper end with a sleeve of resilient material of rubber or the like, through which a stacked and nested assembly comprising briquets of the material to be melted are progressively fed from the exterior of the housing down through the tubular receptor and into the crucible and thence to the arc through the lower portion of the receptor which projects into the crucible. As the briquets are thus fed progressively into the crucible and successively arc melted therein to build up the ingot, the tubular receptor is progressively elevated so that its lower end always clears the ingot. Meantime, additional briquets are added to the nested stack exteriorly of the housing and fed successively through the receptor into the crucible as aforesaid. For properly centering the briquets in stacked assembly as above stated, they are preferably formed with complementary tongues and cavities at their upper and lower ends so that the tongue of one briquet will fit within the cavity of the succeeding or lower briquet. Also, if desired, the briquets may be spot welded together as successive briquets are mounted on the top of the stack and fed into the tubular receptor. However, when this latter technique is employed care must be taken to prevent contact between the hot welds and the resilient sleeve, since such contact results in deterioration of the sleeve. According to the invention such contact is avoided by arc-welding the briquets in such manner that the resultant welds are located well beneath the external cylindrical surface of the electrode, so that as the welded briquets pass through the sleeve, these welds do not touch the sleeve.

During this feeding, the resilient sleeve referred to provides a substantially gas-tight seal which prevents entry of the outer atmosphere into the furnace. As a further precaution against entry of atmospheric gases into the furnace, the upper end of the tubular receptor is appropriately apertured as is also the resilient sleeve thereof, and pipe fittings secured thereto for flushing the briquets with an inert gas such as argon upon entry into the upper portion of the receptor and similar fittings are provided at a lower level of the receptor for evacuating the thus flushed briquets by a vacuum applied to the pipe fittings last mentioned.

It has been found that in the melting of titanium sponge and the like, considerable outgassing occurs during the melting due to the elevated temperature evolution of absorbed gases such as oxygen, nitrogen, hydrogen, etc. This outgassing tends to produce a porous ingot and one which is embrittled by these contaminants if permitted to remain in contact with the ingot as the melting and building up of the ingot proceeds.

As a further feature of the invention, this objectionable feature is eliminated by producing a continuous flow of inert gas into and out of the crucible as the melting proceeds. This is effected by introducing an inert gas such as argon, through a pipe line which extends to and provides outlet substantially at the region of the arc and by further providing in the furnace an evacuating outlet for said gas. Thus, during the melting, the inert gas introduced continuously under pressure sweeps over the upper level of the molten metal and past the arc, conveying with it all evolved gases which are swept thence out of the furnace through the evacuating outlet.

Having thus described the invention in general terms, reference will now be had, for a more detailed description of this and other features of the invention, to the accompanying drawings wherein:

Fig. 1 is a vertical elevation view of the complete furnace apparatus according to a preferred embodiment of the invention.

Fig. 2 is an enlarged vertical sectional view of the lower portion of the furnace apparatus of Fig. 1, showing in detail the arc-melting crucible thereof and appurtenant components.

Fig. 3 is an enlarged fragmentary sectional view showing the flow path of inert gas through the fittings provided in the upper end of the tubular receptor and the resilient sleeve thereof for purging the porous briquets of the electrode.

Fig. 4 is a horizontal cross-section taken on the line 4—4 of Fig. 1 looking in the direction of the arrows and showing the water-cooled jacket surrounding the electrode receptor.

Fig. 5 is an enlarged vertical sectional view of an upper portion of the furnace of Fig. 1, showing in detail the sealing sleeve of the electrode receptor.

Fig. 6 is an enlarged fragmentary sectional view showing the retaining jaws of the electrode receptor in detail.

Fig. 7 is a horizontal cross-sectional view showing the action of the retaining jaws clamping the briquets.

Fig. 8 is a top plan view of the furnace housing showing the removable cover thereof.

Fig. 9 is a vertical sectional view similar to Fig. 5 but showing an electrode formed of briquets spot welded together.

Fig. 10 is a partial side elevational view of an alternative embodiment of a spot welded briquet electrode.

Referring now to the drawings and particularly to Figs. 1 and 5 thereof, the electric arc-melting furnace according to the invention comprises a furnace housing **10** of the conventional "cold-mold" type, having an upper water-cooled tank portion **11**, provided with coolant inlet and outlet connections **12** and **13**, and a lower water-cooled crucible portion **14**, provided with coolant inlet and outlet connections **15** and **16**. This furnace housing is sealed off from the atmosphere by means of a removable cover plate **17**, which is also water-cooled as indicated at **18**. A plurality of toggle bolts **19** serve to clamp this cover to the housing and as shown in Fig. 8, these toggles can, when desired, be loosened and swung outwardly, thereby permitting removal of the cover. A vacuum line connection **20** is provided in the side wall of the tank portion **11** of the housing, and suitable vacuum pump means are attached thereto whereby the gases may be drawn off from the interior of the furnace chamber and the melting operations carried out under the desired low pressure conditions. Mounted within the lower portion **14** of the housing is a thin-walled copper crucible **21**, supported in spaced relation to the housing by a ring flange **22** welded to the upper end of the crucible, and which in turn is carried by a corresponding ring flange **23** welded to the furnace housing as shown in Fig. 2. The coolant thus circulated between this lower portion of the housing and crucible **21** thereby cools both components.

The housing cover **17** is provided with a central aperture **24**, and secured to the upper side of said cover in alignment with this aperture by means of fasteners is a flanged sealing sleeve **26**, fitted with annular gaskets **27** of rubber or the like. This sealing sleeve **26** is designed to receive in gas-tight, sliding relationship a water-cooled electrode receptor **28**, which receptor is adjustably suspended over the furnace housing **10**, by means of an hydraulic piston and cylinder assembly **29**, **30** which is fixedly supported from an upright stanchion **31**, by means of horizontally extending braces **32**. The piston and cylinder assembly **29**, **30** is of conventional type with cylinder **30** being provided with hydraulic fluid connections **33**, **34** for raising and lowering piston **29** the latter being connected to a downwardly extending piston rod **35**, the vertical position of which relative to the cylinder can, of course, be controlled as desired by means of the fluid

connectors **33**, **34**. Connected to this piston rod for vertical movement therewith is a frame member **36** which carries at its lower end the electrode receptor **28**. The frame **36** is designed to support an arbor press **37** in operative position above the electrode receptor.

The electrode receptor **28** is supported above the furnace chamber, as above described, with its lower end extending through sealing sleeve **26** and aperture **24** of the housing cover into the furnace chamber itself. This electrode receptor is tubular in form and is provided with a central passageway **38** extending throughout its length and designed to permit passage of an electrode therethrough. As best seen in Fig. 5, the upper portion of the electrode receptor comprises a cylindrical metal sleeve **39** having flanges **40**, **41** welded to its extremities. Flange **40** is suitably secured to the lower end of frame **36** with an insulating ring **42** and cap **43** interposed therebetween, as shown, so as to preclude conduction of electric current between the frame and electrode receptor, while flange **41** is suitably secured to a similar flange **44** of a jacketed, water-cooled tube **45**, which tube comprises the lower portion of the electrode receptor. The upper portion **39** of electrode receptor **28** is lined with a resilient sealing sleeve **46**, made of rubber or equivalent material, which may be formed of three segments **46***a*, **46***b* and **46***c*, and longitudinally spaced apart so as to form annular apertures **46***d* and **46***e* extending through the sealing sleeve. The inner surface of this sealing sleeve **46** is formed with circular corrugations **47**, as shown, which are designed to provide an effective gas-tight sealing relationship with a consumable electrode **48** as the latter is forced through the sleeve under the action of arbor press **37**, as will be described more fully hereinafter. This upper portion of the tubular receptor is provided with an inert or argon inlet connection **49** and a vacuum connection **50**, which extends through the side walls of the metal sleeve **39** into communication with apertures **46***d*, **46***e*, of the sealing sleeve **46**, for gaseous contaminant purging of the electrode itself prior to its entry to the furnace chamber in a manner to be described hereinafter.

The tube **45** which comprises the lower portion of the electrode receptor may be made of copper or its equivalent, and is formed of spaced inner and outer walls **51**, **52** providing a cylindrical cooling jacket. Provided at the upper end of the said tube is a manifold **53** having coolant inlet and outlet connections **54**, **55**.

The consumable electrode **48** is formed, as best seen in Figs. 5 and 6, of a plurality of individual nesting briquets **56**, each provided at one end with a longitudinally extending tongue **57** and at the opposite end with a corresponding complementary depression or cavity **58**. As shown, the cavity **58** of one briquet is adapted to receive in nesting relationship the tongue **57** of the next adjacent briquet so as to thereby form a unitary electrode assembly. In the embodiment shown, these cooperating tongues and cavities **57**, **58** are frustro-conical in shape, but it should, of course, be understood that this is but one of many specific configurations which may be employed.

As described above, the arbor press **37** is supported by frame **36** in operative position above the electrode receptor **28**. This arbor press includes a pilot block **59** which may be formed of hard wood and has a frustro-conical peripheral surface **60**, designed to cooperate with the cavity **58** in the uppermost briquet of the electrode structure. As shown, after a plurality of the individual briquets have been stacked nesting together so as to form the electrode, downward pressure is applied via the pilot block of the arbor press to the uppermost of said briquets, thereby forcing the lower briquets of the electrode successively through the entry sealing sleeve **46** of the electrode receptor **28**. Each of these briquets is formed, as aforesaid, by pressing titanium sponge or other comminuted material into the desired configuration, which

in the embodiment shown, is cylindrical in outer cross-section. In any event, said briquets are formed with external dimensions such as will permit forcible, but tight sealing entry into the electrode receptor through its rubber sealing sleeve **46**.

Referring now to Figs. 2, 6 and 7, the lower end of the copper tube **45** which comprises the lower portion of the electrode receptor is cut away as shown at **61** to provide a pair of electrode retaining jaws **62, 63**. A collet clamping ring **64** having a retaining set screw **65** surrounds the tube **45** at a point intermediate the length of these retaining jaws. The jaws are externally tapered downwardly and inwardly to their tips **66, 67** and the collet clamping ring **64**, has a complementary internal taper. The internal diameter of this collet ring is sufficient to permit the same to be slipped freely over the tips **66, 67** of the jaws, as shown in dotted line in Fig. 6 but when the ring is moved upwardly along the jaws to the position shown in full line in Fig. 6, its internal tapered surface will be brought into contact with the complementary external taper of the jaws themselves, thereby forcing the tips of said jaws together so as to grip the briquets of the electrode. The pressure exerted by said jaws against the electrode briquets can of course be adjusted by varying the vertical position of the collet ring on the jaws. The collet ring set screw **65** is designed to prevent accidental slippage of the ring during operation. Since the collet clamping ring is positioned at a level above the tips of these retaining jaws, the inherent spring action of said jaws will permit them to flex slightly, thereby allowing for slight dimensional variations in the individual briquets while still continuously maintaining a good frictional grip on the same. This continuous gripping action is necessary since, besides the normal force of gravity, due to the low pressure operating conditions in the furnace chamber itself as opposed to the atmospheric pressure acting on the exposed upper end of electrode **48**, there is a pressure differential acting on the briquets which seeks continuously to force them downwardly out of the tube and into the furnace chamber. Moreover, as mentioned above and indicated at **68**, electric current to establish the melting arc is supplied to the electrode via tube flange **41** and tube **45**. This current is, of course, conducted down the jaws of the tube and therefore, if the electrode **48** is to be continuously supplied, continuous contact between the same and said jaws is essential.

The aforementioned downward feeding movement of the briquets under the action of the arbor press is continued until the bottom of the lowermost briquet extends slightly beyond the tips **66, 67** of the retaining jaws. At this point an arc is struck by delivering voltage of positive potential to the connection at **68** from whence current flows down the electrode receptor and retaining jaws to the electrode itself and thence to the crucible. In this position the tips **66, 67** of the clamping jaws will be forced under the action of the collet clamping ring into current conducting contact with the consumable electrode **48**. The electric arc will, of course, cause the end of the lowermost briquet to melt, thereby forming a molten pool **69** in the lower portion of the crucible, and in order to compensate for this melting of the electrode, as mentioned previously, it is necessary to progressively feed the same further downward into the electrode receptor, this being accomplished by additional downward movement of the arbor press **37**, which latter may, of course, be controlled either manually or by suitable automatic control means.

As each briquet emerges from the jaws it is melted and consumed by the arc between them and the molten pool which forms on the top of the ingot. Since these briquets have not been welded together and are merely stacked in nesting relationship, they are, of course, free to move longitudinally relative to one another and therefore means must be provided to prevent the lowermost

briquet from dropping into the molten pool once its peripheral surface has passed out of contact with the tips of the retaining jaws. By properly dimensioning the longitudinal tongues and cavities of said briquets to be of sufficient length, an operating condition can be created so that before the lowermost briquet of the electrode has passed completely beyond the tips **66, 67** of the retaining jaws, the lower end of the tongue **57** of the next upper succeeding briquet will have begun to be melted by the arc, thereby causing that tongue to fuse as indicated at *58a* to the walls of the cavity **58** of the lowermost briquet. Thus, even after the lowermost briquet has passed beyond the tips of the retaining jaws under the action of the arbor press, it will remain fused to the next upper briquet of the electrode which will, of course, still be gripped by the retaining jaws. Thus, by the melting and sintering action of the arc itself, the lowermost briquet is prevented from dropping into the molten pool until it is completely melted.

In order for this fusion of the adjacent briquets to be carried out as desired, besides the necessity of properly dimensioning the tongue and cavity portions of the briquets themselves, it is also, of course, necessary to carefully control the rate of emergence of these briquets from the jaws and also to carefully control the spacing between the jaws themselves and the surface of the molten pool on the top of the ingot. The rate of emergence of the briquets is, of course, determined by the movement of the arbor press **37**, while the spacing of the tips of the jaws of the electrode receptor relative to the surface of the molten pool is controlled by the hydraulic piston and cylinder assembly **29, 30**.

If the rate of downward movement applied via the arbor press to the electrode is too slow, a condition will result wherein not enough of the electrode will project beneath the jaws of the electrode receptor and therefore said jaws will themselves be damaged by the arc. To prevent this, a warning signal means is provided to inform of this improper condition and consequently either by manual or automatic means cause additional downward movement to be applied to the electrode via the arbor press. In the embodiment shown, this signal means comprises a length of wire **70**, made of molybdenum or equivalent high melting point metal which is compatible with the metal being melted in the furnace, and having a loop **71** formed at its lower end and positioned at a predetermined distance beneath the tips **66, 67** of the retaining jaws and surrounding in the spaced relation the lowermost end of electrode **48**. This signal wire is attached at its upper end via a connector to one end of a coil spring **73**, the other end of which is attached to a conducting terminal **74** which extends through the cover **17** of the furnace housing and connects with through a lead **75** to one terminal of an ammeter, the opposite terminal of which is connected to ground. In operation, when there is an insufficient amount of the electrode projecting downwardly beneath the jaw tips, the electric arc will strike the molybdenum wire loop **71**, thereby sending a measurable current from the molten pool on top of the ingot to said loop and up the wire **70**, spring **73**, terminal **74** and lead **75** to the warning current recording instrument. In actual practice, when such a current is recorded the arbor press will then be operated either manually or automatically, as desired, to eject more of the consumable electrode structure from the lower end of the electrode receiving tube.

On the other hand, as melting of the lower end of the consumable electrode proceeds, the size of the ingot formed in crucible **21**, of course, increases and consequently the molten pool **69** on top of the ingot moves closer to the tips of the retaining jaws of the electrode receptor. When this vertical spacing between the jaws and molten pool falls below a predetermined value, the arc voltage will drop to a value which is insufficient for

proper melting action and when this occurs the entire electrode receptor is retracted to the desired distance above the surface of the melt by suitably controlling hydraulic piston and cylinder assembly **29**, **30**.

As mentioned above, the consumable electrode may also be formed of a plurality of briquets spot welded together. As shown in Fig. 9, such an electrode **90** is comprised of a plurality of porous briquets **91** of the material to be melted. The ends of these briquets are oppositely chamfered as at **92** and **93** so that, when stacked in end-to-end relationship, circumferentially extending, V-shaped grooves or cutout portions **94** are provided between adjacent briquets. Prior to their entry into the tubular electrode receptor **28** a number of briquets **91** may be stacked in such end-to-end relationship and adjacent ones joined together by means of a plurality of spot welds **95**, said welds being spaced circumferentially about and disposed entirely within the V-shaped grooves **95**. As successive briquets are stacked and welded together so as to form electrode **90**, they are fed under the action of the arbor press **37** through the entry sealing sleeve **46** of the electrode receptor. When such an electrode **90** is used, the arbor press **37** is provided with a flat surfaced pilot block **96** designed to cooperate with the flat upper end of **97** of the uppermost briquet of the electrode. As was true of electrode **48** described above, the briquets of electrode **90** are formed with external dimensions such as will permit forcible, but tight sealing entry into the electrode receptor through its sealing sleeve. As shown, by properly dimensioning the V-shaped grooves **94** and positioning the welds **95** entirely within said grooves, a radial clearance can be maintained between the external surface of said welds and the internal, corrugated surface of the sealing sleeve **46**, whereby the electrode can be forced in tight sealing relationship through said sleeve without contact between the latter and the welds. As mentioned above, if the hot weld surface were permitted to contact the sleeve, deterioration of the latter would result thereby destroying its effectiveness. In Fig. 10 an alternative form of welded briquet electrode **100** is shown. Electrode **100** is comprised of a plurality of briquets **101**, similar in composition to briquets **91**, but having a plurality of semicylindrical cutouts **102**, **103** formed at opposite ends. When a plurality of such briquets **101** are stacked in end-to-end relationship with the cutouts **102**, **103** aligned, a plurality of radially inwardly extending cylindrical notches **104** are formed between adjacent briquets. These briquets are then joined together by spot welding within the cylindrical notches **104**. Once again it should be noted that said notches are so dimensioned and the welds so located entirely therewithin that a radial clearance will be maintained between the outer surface of the welds and the inner surface of the sealing sleeve **46** as the electrode **100** is forced therethrough under the action of arbor press **37**.

As mentioned above, the briquets which make up the consumable electrode are porous and therefore will contain a certain amount of harmful gaseous constituents such as hydrogen, oxygen, nitrogen, etc., and unless means are provided for effectively removing these, there will ultimately be absorption thereof by the melt, resulting in contamination and embrittlement of the ingot produced. To this end, the upper portion of the electrode receptor is provided with inert gas inlet and vacuum connections **49**, **50**, as hereinbefore described. As the nested briquets of the electrode are forced through the resilient sleeve **46** by the arbor press, an inert gas under slight pressure, for example, argon at one pound per square inch above atmospheric pressure, is introduced through passage **49** and, as shown in Fig. 3, will flow in the direction of arrows A and disperse through the pores of the briquets and will eventually pass on out through vacuum port **50** as indicated by arrows B, this latter port being of course suitably connected to a vacuum pump. As this inert gas flushes through the pores of the briquets, it will serve to purge therefrom the harmful gaseous constituents which may be there present, with the result being that said constituents will pass along with the inert gas on out through the vacuum port prior to the entry of the electrode into the furnace chamber.

As an added precaution against contamination of the melt due to absorption of harmful gaseous contaminants, the present invention provides an inert gas sweep mechanism which is designed to remove from the furnace housing any harmful volatiles which may collect above the melt. If such contaminants are not removed as evolved, by the inert gas purging action described above, upon heating the same will collect in volatile form in the furnace chamber above the surface of the melt. To remove such harmful volatiles before their absorption by the melt, a conduit **76** is led into the furnace chamber and positioned so that its end **77** terminates in close proximity to the surface of the molten pool **69**. This conduit **76** can be formed of molybdenum or any other high melting point metal which is compatible with the metal being melted in the crucible. By this proper selection of metal, the conduit will withstand the high temperatures in the furnace except for its lower end **77** which will gradually melt away, as indicated at **78**, as the surface of the melt itself rises in the crucible, thereby bringing the electric arc closer to the end of said conduit. Argon or a similar inert gas is continuously introduced under pressure through conduit **76** and thereby delivered directly to the vicinity of the surface of the melt. Suitable vacuum pumping means are attached to furnace chamber vacuum conduit **20** and are continuously driven during the furnace melting operation, thereby causing the mixture of argon and harmful volatiles in the furnace to be drawn off through the vacuum conduit **20**. By delivering this inert gas sweep directly to the vicinity of the melt, the collection of harmful volatiles over that melt is readily eliminated, the same being driven or swept forward toward the vacuum connection **20** under the combined action of the pressure of the sweep itself and the evacuating action of conduit **20**. If it is desired to make this sweeping action even more positive and vigorous, the vacuum connection **20** may itself be located in close proximity to the surface of the melt, thereby providing a shorter and more definite inert gas sweep path.

In providing such an inert gas sweep mechanism, care must be taken lest the desired ingredients of the melt themselves volatilize, rise from the surface thereof and, as a result, be swept out of the furnace along with the aforementioned harmful volatiles. In this regard, it will be understood that, during the conventional "cold-mold" process of melting, the furnace chamber is maintained at a predetermined low pressure. However, care must be taken to maintain this furnace operating pressure at a sufficient level to prevent volatilization of the desired ingredients of a particular melt. Thus, for example, when titanium-manganese alloys containing about 7% manganese are being melted, it has been found that unless the pressure in the furnace chamber is maintained at or above 30 mm. of mercury absolute pressure, the manganese content of the melt will volatilize and be driven off by the argon sweep through vacuum connection **20**, thereby undesirably affecting the final manganese content of the alloys melted. While 30 mm. is, therefore, the minimum satisfactory operating pressure for manganese alloys, it has been found that much lower operating pressures may be used for titanium base alloys containing alloying contents of aluminum, chromium, iron, vanadium, molybdenum and tin, and, on the other hand, that in the case of antimony additions, the minimum operating pressure may be as high as 100 mm. mercury absolute. It seems probable that in general the minimum satisfactory operating pressure depends upon the vapor pressure of the particular alloying ingredients in the melt or, in other words,

the pressure of the inert gas above the melt must be greater than this vapor pressure in order to prevent boiling away of the alloying ingredients.

If, for example, a titanium-manganese alloy is being melted and it is desired to maintain the furnace chamber at 30 mm. mercury absolute, argon at atmospheric pressure and at a rate of from one to two cubic feet per minute is delivered to the sweep conduit **76**, while the vacuum pumps connected to vacuum outlet **20** will be geared to pump out the furnace chamber gases at a rate of twenty-five to thirty cubic feet per minute. Since an argon flow of from one to two cubic feet per minute at atmospheric pressure amounts to a flow of twenty-five to thirty cubic feet per minute at 30 mm. mercury, the pressure of the inert gas above the surface of the melt will be maintained at 30 mm. mercury. If it should be desired to operate at pressures lower than 30 mm., the vacuum pumps can maintain the same rate of gas outflow, while the rate of argon feed to sweep conduit **76** is proportionately reduced.

By directing this low pressure argon sweep to the vicinity of the melt by a conduit **76** or similar means, violent convection currents will stir up the harmful volatiles positioned over the melt and cause the same to mix effectively with the inert gas and be swept out through vacuum conduit **20** under the action of the pumps as aforesaid.

Although certain particular embodiments of the invention are herein disclosed for purposes of explanation, various further modifications thereof, after study of this specification, will be apparent to those skilled in the art to which the invention pertains. References should accordingly be had to the appended claims in determining the scope of the invention.

What is claimed is:

1. An electric arc-melting furnace which comprises: a substantially gas-tight furnace chamber; a tubular electrode receptor slidably extending from the exterior to the interior of said chamber through an upper wall thereof; a resilient, substantially gas-tight sealing means interposed between said receptor and said upper furnace wall; means external to said chamber for raising and lowering said receptor; a resilient lining for said receptor, disposed adjacent the upper end thereof, adapted to permit an electrode to be fed progressively therethrough into said chamber while substantially preventing the entry of atmospheric gases thereinto; and means external to said chamber for progressively feeding said electrode through said receptor into said chamber.

2. An electric arc-melting furnace which comprises: a substantially gas-tight furnace chamber; a tubular electrode receptor slidably extending from the exterior to the interior of said chamber through an upper wall thereof; a resilient, substantially gas-tight sealing means interposed between said receptor and said furnace wall; means external to said chamber for raising and lowering said receptor; a resilient lining for said receptor disposed adjacent the upper end thereof, adapted to permit an electrode to be fed progressively therethrough into said chamber while substantially preventing entry of atmospheric gases thereinto; and means external to said chamber for progressively feeding briquets of a consumable electrode material, progressively through said receptor and into said chamber.

3. An electric arc-melting furnace which comprises: a substantially gas-tight furnace chamber; a tubular electrode receptor slidably extending from the exterior to the interior of said chamber through an upper wall thereof, a resilient, substantially gas-tight sealing means interposed between said receptor and said furnace wall; means external to said chamber for raising and lowering said receptor; a resilient lining for said receptor disposed adjacent the upper end thereof, adapted to permit an electrode to be fed progressively therethrough into said chamber while substantially preventing entry of atmospheric gases thereinto; and means external to said chamber for progressively feeding briquets of a consumable electrode material, progressively through said receptor and into said chamber, said tubular electrode receptor being provided at its lower end with a resilient retaining means for retaining said briquets in stacked assembly within said receptor during said progressive feeding of said briquets and the arc-melting thereof as they are progressively fed through the lower end of said receptor.

4. An electrode arc-melting furnace which comprises: an elongated, upstanding furnace housing, a crucible disposed within the lower portion of said housing, a tubular electrode receptor slidably extending from the exterior to the interior of said housing through an upper wall thereof, a resilient, substantially gas-tight sealing means interposed between said receptor and said upper furnace wall; means external to said housing for raising and lowering said receptor; a resilient lining for said receptor, disposed therein within the upper portion of said housing above said crucible, and adapted to permit an electrode to be fed progressively therethrough from the exterior of said housing into said crucible, while substantially preventing the entry of atmospheric gases into said housing and crucible; and means external to said housing for progressively feeding said electrode through said receptor and into said crucible.

5. An electric arc-melting furnace which comprises: an elongated, upstanding furnace housing; a crucible disposed within the lower portion of said housing; a tubular electrode receptor extending from the exterior to the interior of said housing through an upper wall thereof; a resilient lining for said receptor, disposed therein within the upper portion of said housing above said crucible, and adapted to permit an electrode to be fed progressively therethrough from the exterior of said housing into said crucible, while substantially preventing the entry of atmospheric gases into said housing and crucible; means external to said housing for progressively feeding said electrode through said receptor and into said crucible; means for introducing an inert gas, under pressure, through an upper portion of said furnace housing, tubular receptor and the resilient lining thereof, and for withdrawing said gas, under vacuum, through a lower portion thereof; and independent means for introducing an inert gas, under pressure, into the lower portion of said crucible, and for withdrawing the same under vacuum.

6. An electric arc-melting furnace which comprises a substantially gas-tight furnace chamber, hollow electrode receiving means extending from the exterior to the interior of said chamber, electrode entry sealing means provided at the upper end of said electrode receiving means, a consumable electrode extending through said sealing and receiving means into the furnace chamber and means for progressively feeding said electrode through the sealing and receiving means into the furnace chamber, said receiving means being provided at its lower end with resilient retaining means adapted to continuously and yieldingly grip the electrode as the latter is fed into the furnace chamber, and said electrode being formed of a plurality of aligned individual briquets each having a longitudinally extending tongue formed at one end and a corresponding longitudinal cavity formed at the other end with the tongue of each briquet being nested within the cavity of the next adjacent briquet.

7. An electric arc-melting furnace which comprises a substantially gas-tight furnace chamber, a hollow electrode receptor extending into said furnace chamber, electrode entry sealing means provided at the upper end of said receptor, a consumable electrode formed of a plurality of nesting briquets, means for feeding said briquets through the sealing means into said receptor and thence into said furnace chamber, resilient retaining jaws provided at the lower end of said receptor and yieldingly engaging said electrode so as to continuously deliver electric current thereto, and warning signal means spaced beneath said retaining jaws and adapted to indicate when the rate of feed of said electrode is too slow.

8. An electric arc-melting furnace which comprises a substantially gas-tight furnace chamber; a tubular electrode receptor extending from the exterior to the interior of said chamber, electrode entry sealing means provided at the upper end of said receptor, a consumable electrode formed of a plurality of porous individual nesting briquets, means for feeding said electrode through the sealing means and receptor tube into said furnace chamber, said sealing means being adapted to provide a sliding but gas-tight fit with the peripheral surface of the electrode and said tube being provided at its lower end with resilient retaining jaws adapted to continuously grip the peripheral surface of the consumable electrode as the latter is fed into the furnace chamber, means provided at said sealing means for flushing the porous interior of said electrode whereby contaminants contained therein are purged therefrom, and vacuum connection means provided in said furnace chamber, together with means to deliver a flow of inert gas under pressure into said furnace chamber near the vicinity of the surface of the melt whereby any harmful volatiles collected above said surface will be swept along with said inert gas out through the said vacuum connection.

9. A furnace for melting titanium and similar metals of the type wherein it is desired to preclude absorption by the resulting melt of harmful gaseous contaminants such as hydrogen, oxygen and nitrogen, which comprises a furnace chamber, tubular electrode receiving means extending into said chamber, means for feeding a consumable electrode through said receiving means into said furnace chamber, means for effectively sealing the chamber from the ingress of harmful atmospheric gases, vacuum connection means provided in said chamber for maintaining the operating pressure in said chamber at a predetermined low level, and inert gas delivery means extending into said furnace chamber and terminating in the vicinity of the surface of the melt so as to deliver a flow of inert gas under pressure to that vicinity whereby any harmful contaminants collected above said melt will be swept out through said vacuum connection.

10. A method of melting titanium or similar type metals in such manner as to prevent contamination of the resulting melt due to absorption of harmful contaminants which comprises feeding a porous, consumable type electrode through a gas-tight seal into the melting chamber of an arc-melting furnace, delivering a flow of inert gas through said sealing means to the porous interior of the electrode whereby said electrode is purged of harmful contaminants which may be present therein, maintaining the melting chamber at a predetermined low pressure and delivering a sweep of inert gas into said furnace chamber at a point closely proximate to the surface of the melt whereby any harmful volatiles which may have gathered above said melt are intermixed with and swept along in the path of said inert gas and out of said melting chamber.

11. A method of melting titanium or similar type metals in such manner as to prevent contamination of the resulting melt due to absorption of harmful contaminants which comprises feeding a porous, consumable type electrode through a gas-tight seal into the melting chamber of a furnace, maintaining the melting chamber at a predetermined low pressure and delivering a sweep of inert gas into said furnace chamber at a point closely proximate to the surface of the melt whereby any harmful volatiles which may have gathered above said melt are swept along in the path of said inert gas and out of said melting chamber.

12. A method of melting titanium or similar type metals in such manner as to prevent contamination of the resulting melt due to absorption of harmful contaminants which comprises melting a charge of such metal in a gas-tight furnace chamber, maintaining said chamber at a predetermined low pressure and delivering a sweep of inert gas into said furnace chamber at a point closely proximate to the surface of the melt whereby any harmful volatiles which may have gathered above said melt are swept along in the path of said inert gas and out of said melting chamber.

13. An electric arc-melting furnace which comprises a substantially gas-tight furnace chamber electrode receiving means extending from the exterior to the interior of said chamber, electrode entry sealing means provided at the upper end of said receiving means and adapted to permit a consumable type electrode to be continuously fed through said receiving means and into said chamber while at the same time substantially preventing the ingress of atmospheric gases thereto, and means for continuously feeding a consumable electrode into said chamber through said receiving means, said receiving means being provided at its lower end with resilient retaining members adapted to continuously and yieldingly engage said electrode whereby electric current can be continuously supplied thereto.

14. An electric arc-melting furnace which comprises: a furnace chamber, a hollow electrode receptor extending into said chamber from the exterior thereof in sliding but substantially gas-tight relationship therewith, said receptor having a pair of downwardly extending resilient retaining jaws at its lower end, a consumable electrode disposed in said receptor and having its lower end gripped by said retaining jaws, an electrode entry sealing means located at the upper end of said receptor said sealing means comprising a cylindrical rubber seal surrounding said electrode in tight gripping, substantially gas-tight relationship therewith and means to progressively feed the electrode past the seal and through the receptor into the furnace chamber.

15. An electric arc-melting furnace which comprises: an elongated, upstanding housing, a crucible disposed within the lower portion of this housing, a tubular electrode receptor extending from the exterior to the interior of said housing through an upper wall thereof, a resilient lining for said receptor disposed adjacent the upper end thereof, a consumable electrode extending through said lining and receptor into the furnace chamber, said electrode having external dimensions such as to permit forcible but tight sealing passage through said lining and being formed of a plurality of aligned individual briquets joined together in end-to-end relationship by means of welds located beneath the external surface of said electrode so as to prevent contact between said welds and the resilient lining.

16. An electric arc-melting furnace which comprises a substantially gas-tight furnace chamber, hollow electrode receiving means extending from the exterior to the interior of said chamber, electrode entry sealing means provided at the upper end of said electrode receiving means, a consumable electrode extending through said sealing and receiving means into the furnace chamber and means for progressively feeding said electrode through the sealing and receiving means into the furnace chamber, said receiving means being provided at its lower end with resilient retaining means adapted to continuously and yieldingly grip the electrode as the latter is fed into the furnace chamber, and said electrode being formed of a plurality of individual briquets joined together in end-to-end relationship by means of welds located beneath the external surface of said electrode so that a radial clearance is maintained between said welds and said sealing means as the electrode is fed therethrough.

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