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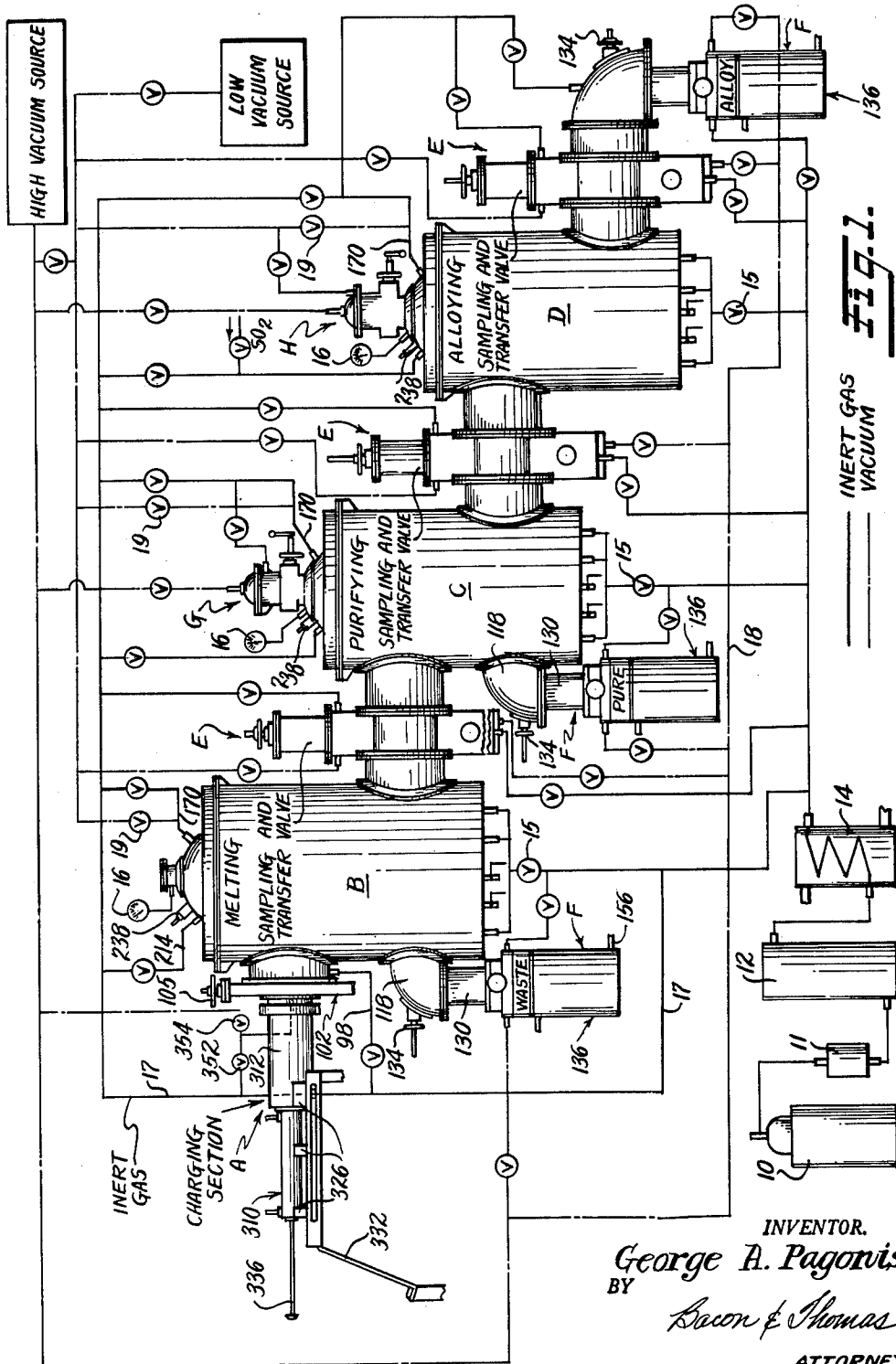
G. A. PAGONIS

3,226,102

CONTINUOUS VACUUM AND INERT GAS APPARATUS FOR TREATING
AND PROCESSING TITANIUM AND OTHER METALS

Filed Jan. 18, 1963

8 Sheets-Sheet 1



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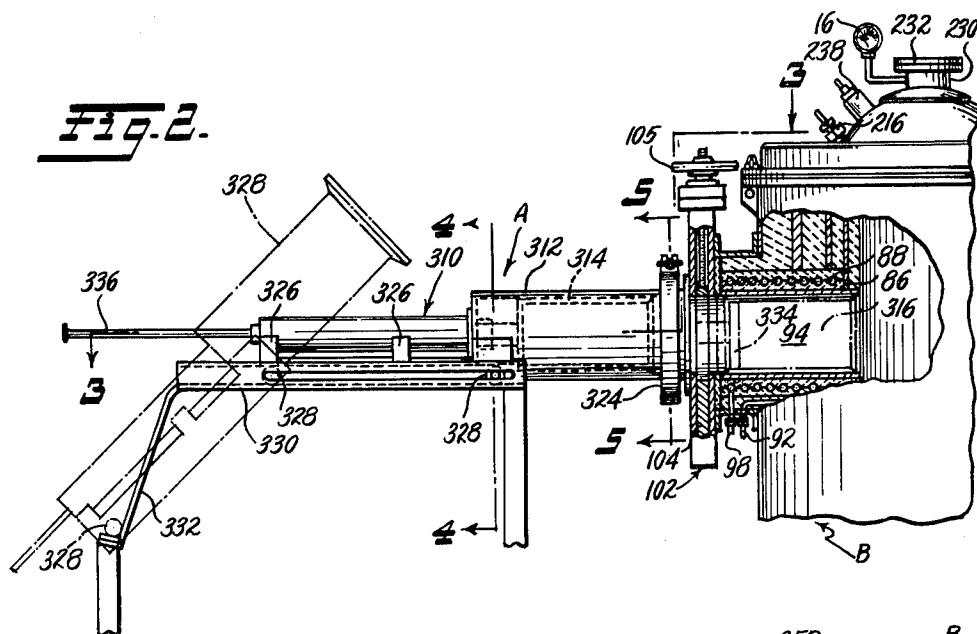
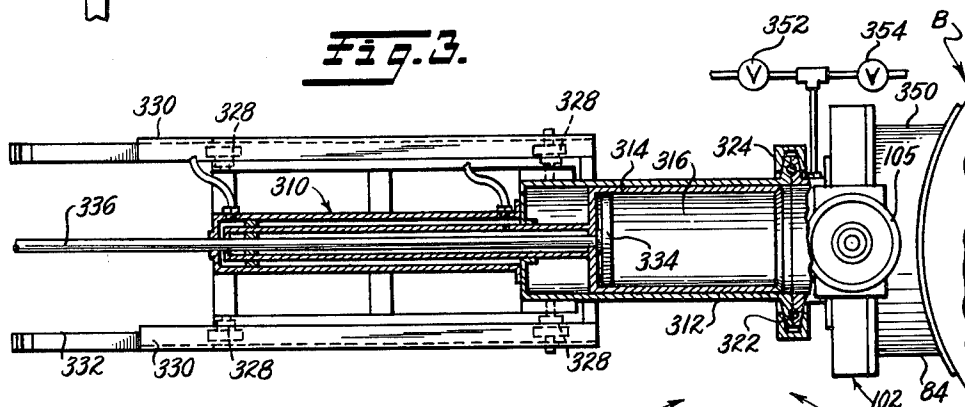
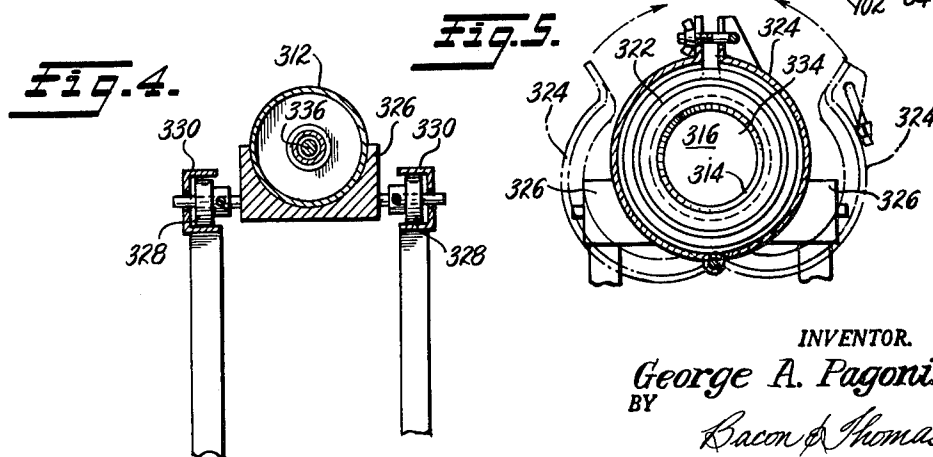
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CONTINUOUS VACUUM AND INERT GAS APPARATUS FOR TREATING
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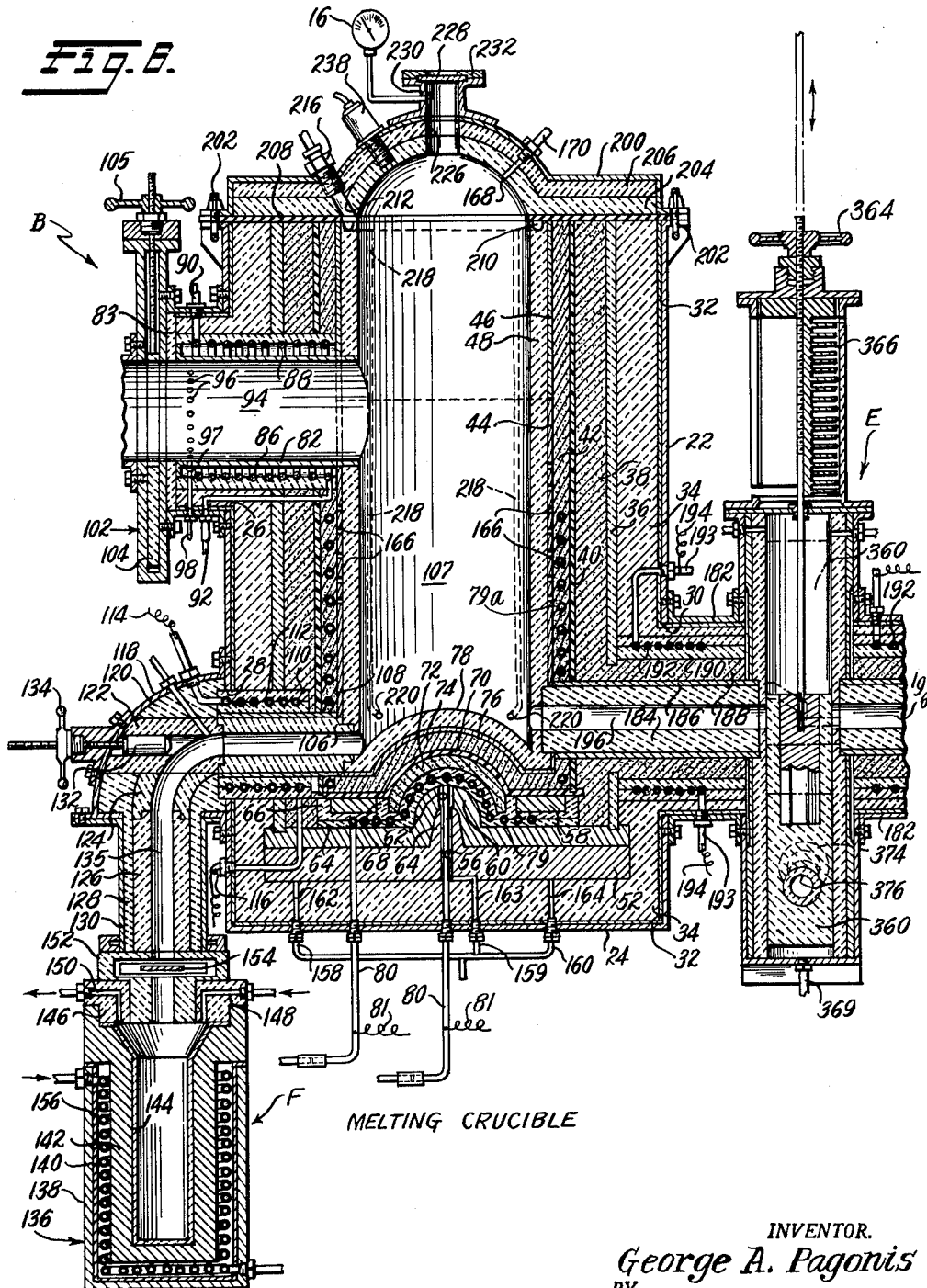
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8 Sheets-Sheet 3



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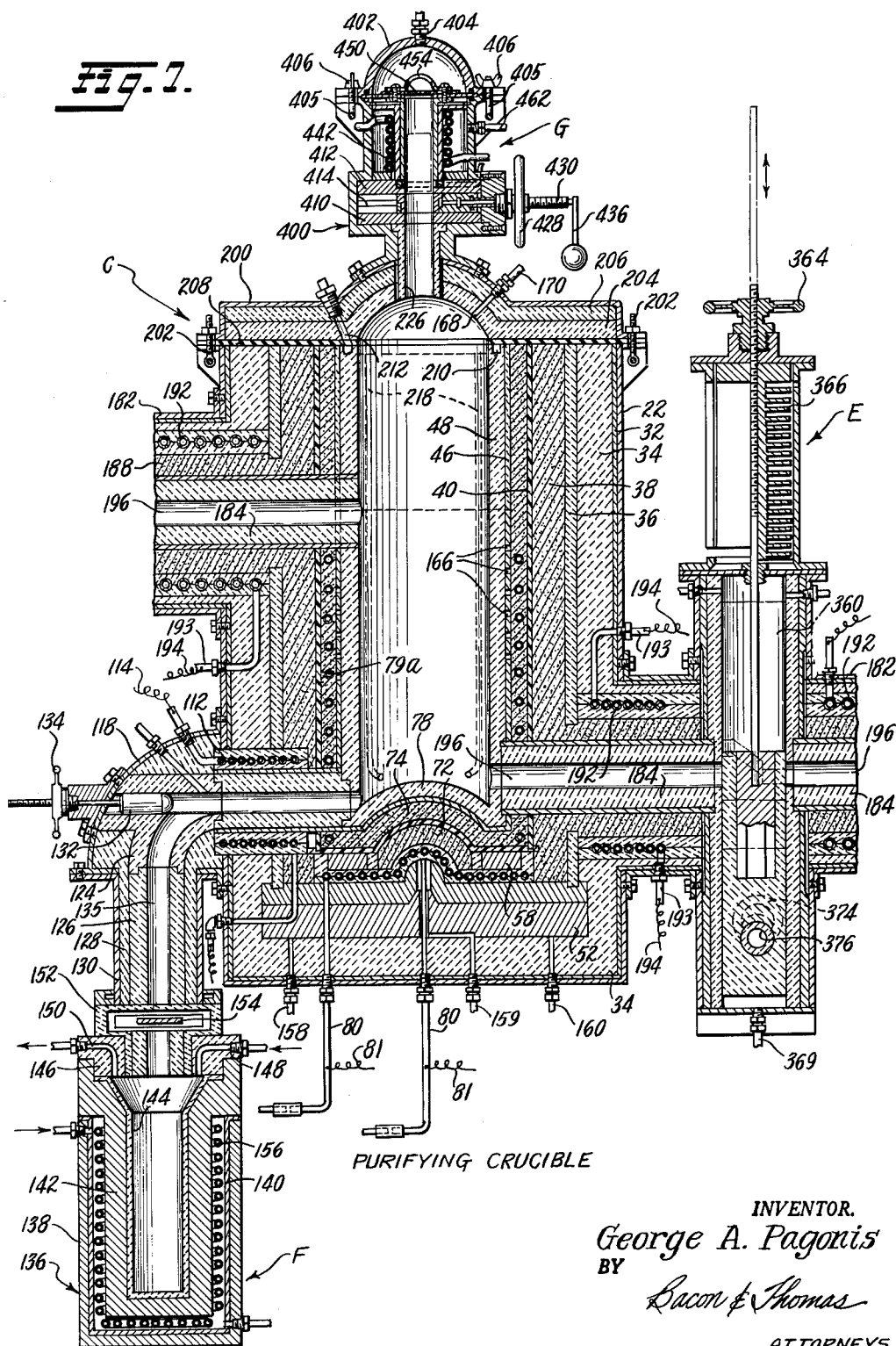
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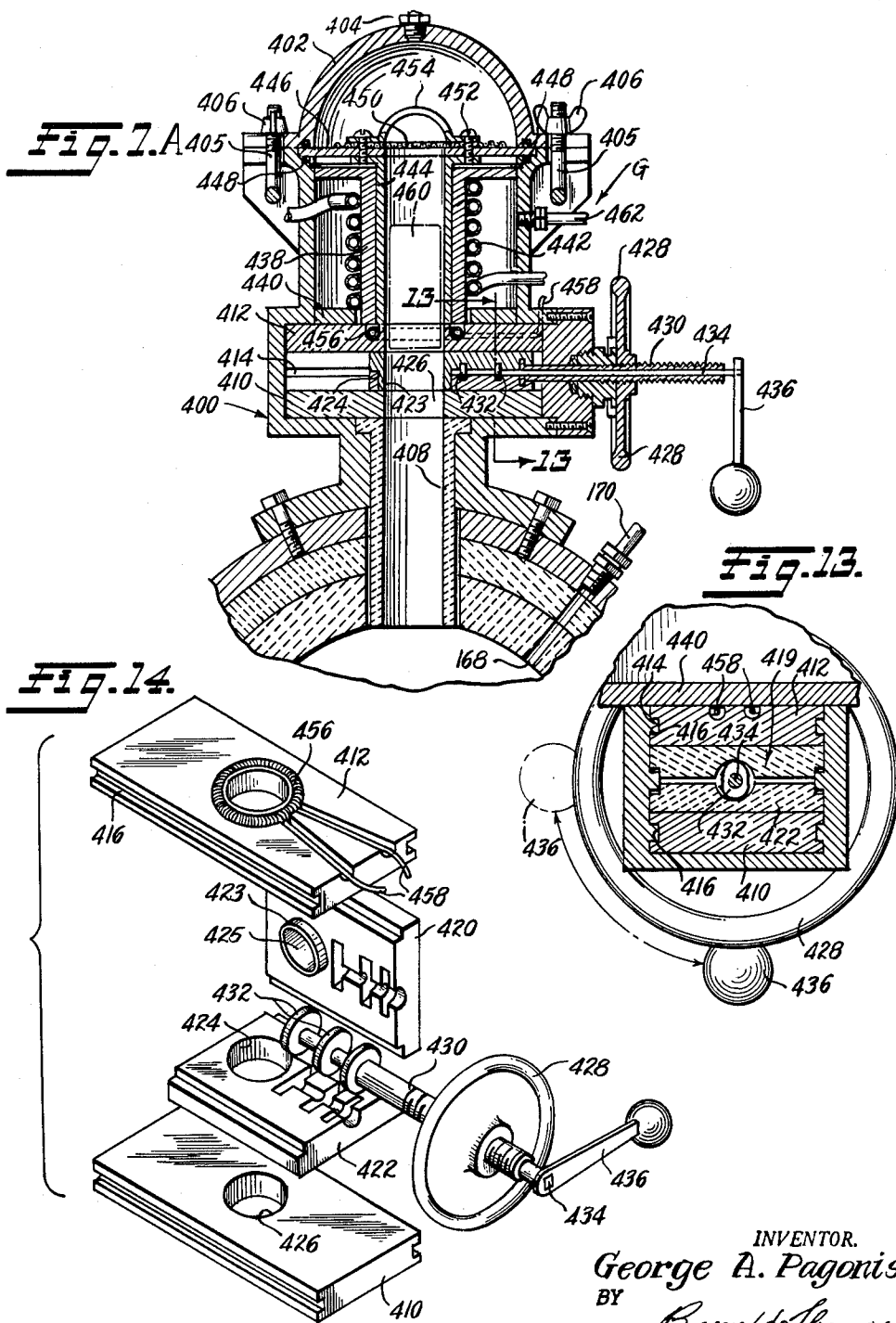
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Filed Jan. 18, 1963

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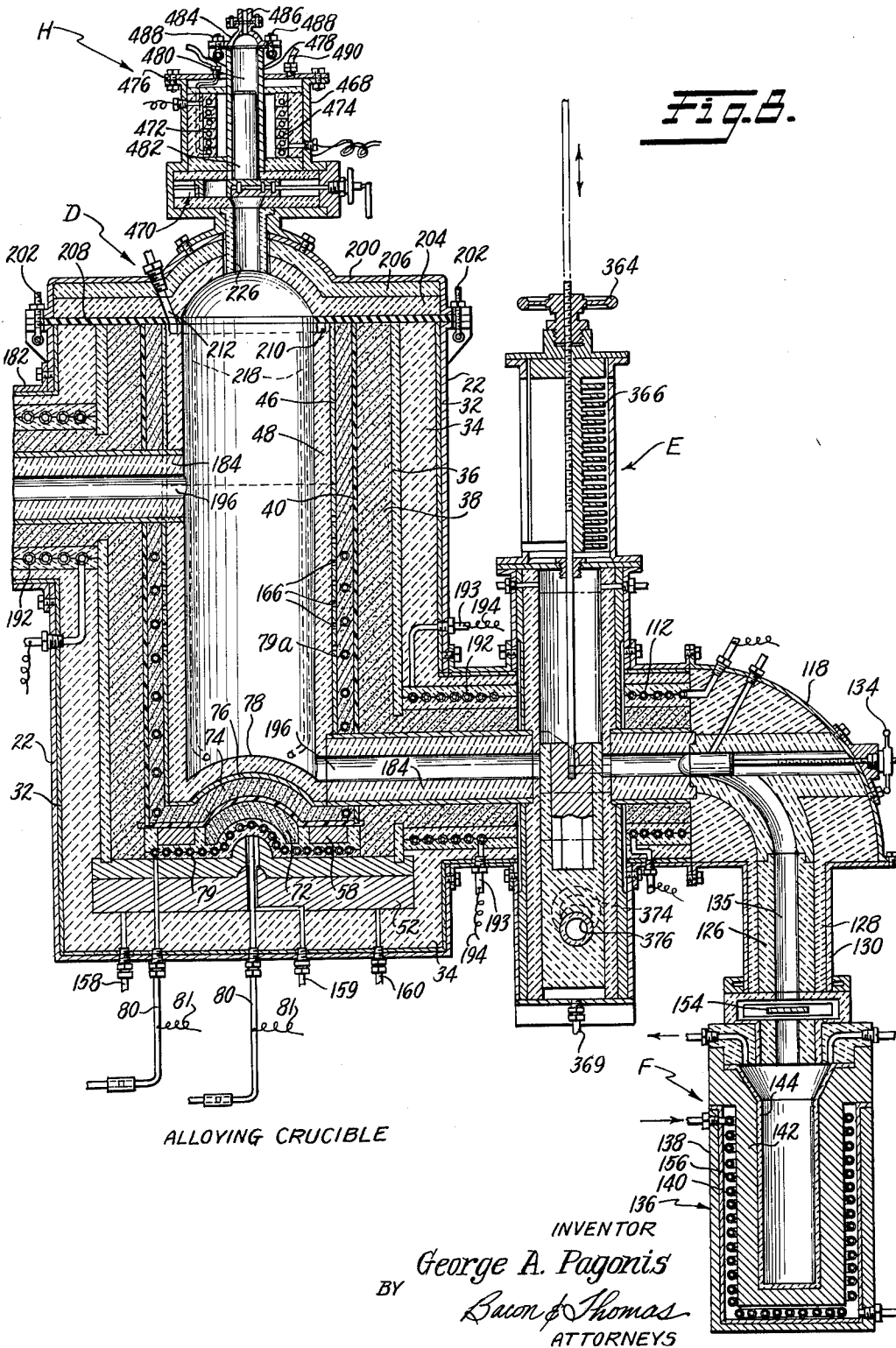
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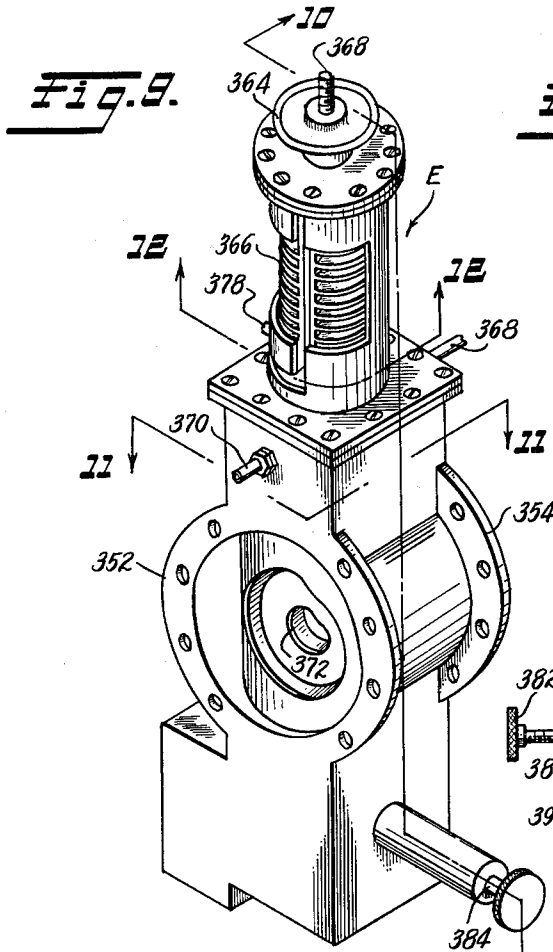
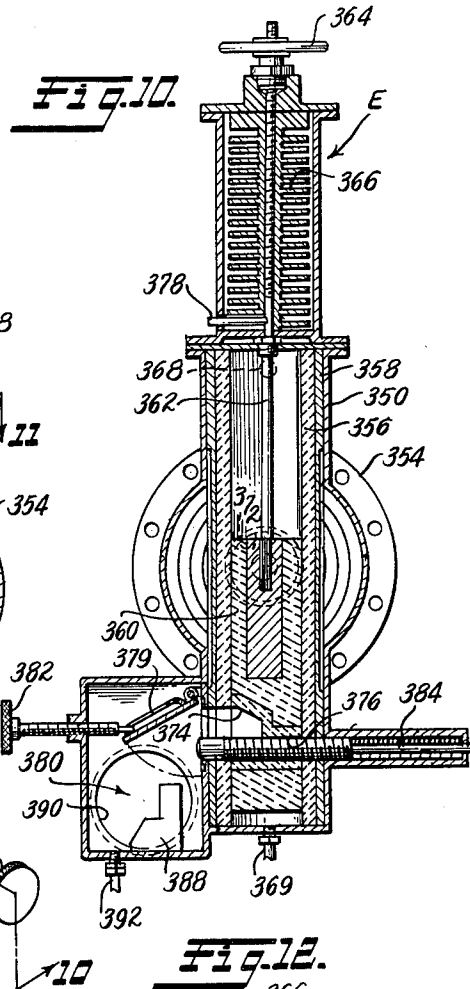
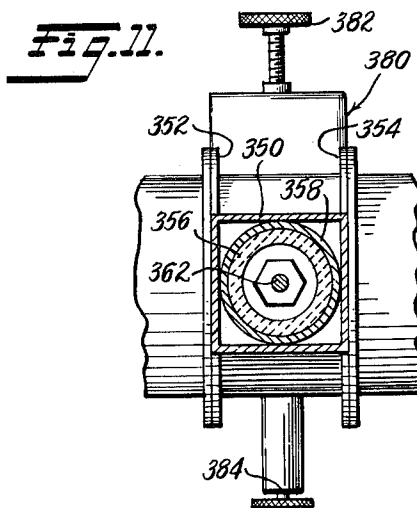
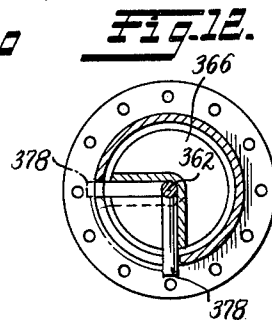
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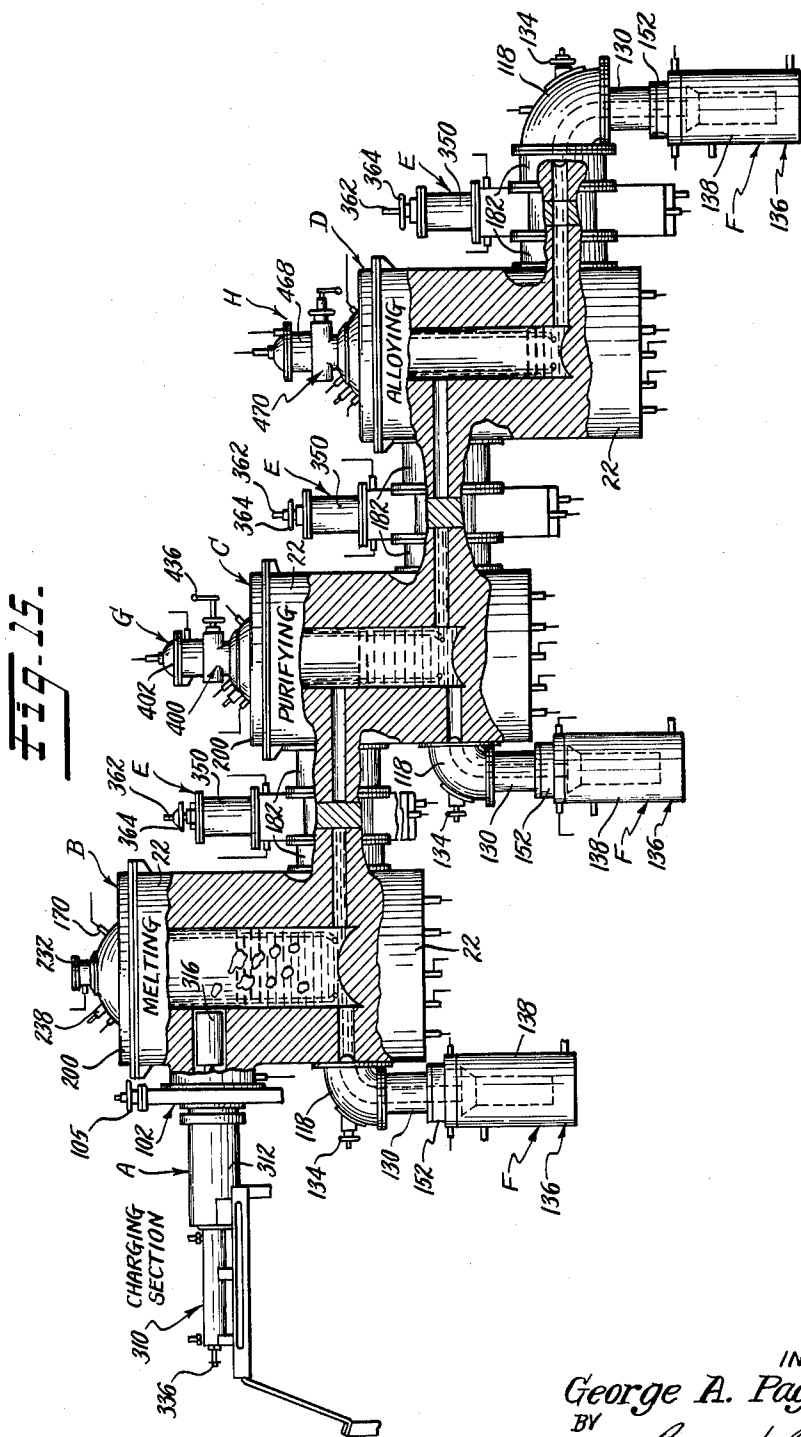
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Filed Jan. 18, 1963

8 Sheets-Sheet 8



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3,226,102

CONTINUOUS VACUUM AND INERT GAS APPARATUS FOR TREATING AND PROCESSING TITANIUM AND OTHER METALS

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Filed Jan. 18, 1963, Ser. No. 252,481

23 Claims. (Cl. 266—34)

The present application is a continuation-in-part of my co-pending applications S.N. 775,994, filed November 24, 1958, now Patent 3,079,451, and S.N. 863,329, filed December 31, 1959, now Patent 3,116,998, which applications are in turn continuations-in-part of my application S.N. 505,887, filed May 4, 1955, now abandoned.

This invention relates to a novel continuous vacuum and inert gas apparatus for treating and processing titanium and other metals. More specifically it relates to an integral, gas-tight, inter-connected, multi-stage, metallurgical system wherein charges of metal to be processed may be repeatedly introduced into a first stage and molten metal may be cast from a subsequent stage after a series of treating operations, each treating operation of which may be selectively isolated from another in the closed system. The apparatus enables metals to be melted, purified, alloyed and cast in physically separated zones of the integral closed system. There is substantially no flow of contaminating gases or other impurities from one zone to the next or from the ambient atmosphere into the system, thereby ensuring the ultimate in purity of the final product. The apparatus is continuous in the sense that, once placed in operation, charges of metal are repeatedly introduced into the first stage, portions of molten metal are repeatedly transferred from stage to stage in treating sequence, and ingots are repeatedly cast from the last stage, but without interruption of the continuity of the process operations, the system at all times containing metal in some stage of a processing operation. Each element of the integral combination cooperates with the associated elements to provide a single unitary result, that is, product purity and consistency and operational simplicity.

Research metallurgists and engineers have long realized that metals and alloys processed by conventional methods and operations have many drawbacks. These are often associated with the presence of indefinite quantities of unavoidable contaminants tending to induce countless structural imperfections. The need to transform the melting and alloying procedures to a more exact science has long been recognized by research metallurgists and engineers all over the world. In line with this research, the batch-vacuum method using electric arc and induction principles, the electro-refining melting methods, the electro-beam and electrode-bombardment melting method and the zone melting and refining method offered definite advantages over the previous methods. Nevertheless, all these methods are of the batch type and have no provisions to hold a molten pool, and are definitely limited in their ability to attain either consistency or homogeneity. The present invention will produce metals and super-alloys which are homogeneously consistent, the apparatus and process lending itself well to such end.

The apparatus of this continuous process invention is especially adapted to the melting, purifying, alloying and casting of metals which are highly reactive at elevated temperatures, such as titanium, beryllium, thorium, zirconium, hafnium and other refractory metals under this category, but can be used also with advantage with all conventional metals, including magnesium, aluminum, copper, iron, etc. and alloys thereof including stainless steel, brass, bronze, etc. The apparatus of the invention

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may be utilized for the recovery of scrap metal, purified and realloyed for the production of ingots, billets and castings of improved property values.

It is an object of this invention therefore, to provide novel continuous apparatus for the production of metals and alloys of superior physical and mechanical properties, and of consistent homogeneous uniformity and structural perfection.

Another object of the invention is to provide a continuous multi-stage metallurgical apparatus for accomplishing a sequence of metal treating operations while the metal is continuously under vacuum or inert gas atmosphere throughout a closed system.

Another object of the invention is to provide a continuous integral multi-stage metallurgical apparatus having interconnected but physically separated zones through which a metal to be treated is sequentially transferred, and in which each zone can be selectively isolated from the other zones during treatment of the metal therein without interruption of the continuity of the process operations.

Another object of the invention is to provide a continuous multi-stage metallurgical apparatus of the type described wherein metal may be charged in a first stage (or zone), treated in subsequent isolated stages (or zones) and withdrawn from a final stage (or zone) while the system is continuously sealed from atmospheric contaminations, without interruption of the continuity of process operations.

Another object of the invention is to provide a continuous multi-stage metallurgical apparatus of the type described wherein charges of solids may be introduced into the various treating stages while avoiding inclusion of impurities and wherein molten metal in each stage may be stirred so as to insure homogeneity in the melt.

Another object of the invention is to provide a closed continuous multi-stage metallurgical system including a novel system for transferring and controlling the flow of molten material between two or more adjacent treating devices in the system.

A further object of the invention is to provide novel means for the introduction of inert gases and for the withdrawal of such gases and impurities from treating stages of a continuous multi-stage metallurgical system.

A still further object of the invention is to provide a continuous multi-stage metallurgical apparatus of the type described, the apparatus being adapted for gas-tight connection between its several component parts, and for operation under inert gas atmosphere and vacuum for each complete cycle of the operation, the construction of the apparatus being such as to preclude the entry of the ambient atmosphere therein at any stage during the operation thereof.

A further object of this continuous apparatus invention is to provide means for the purification of metals and alloys which will permit the additions of preselected scavenger elements tending to remove impurities from the melt by sublimation and without interruption of the continuity of the process operations.

A still further object of this continuous multi-stage apparatus invention is to provide means for carrying out a unique method to further purify a molten metal by exerting pressure on top of molten metal causing residual contaminants to segregate at the bottom of the crucible and to accomplish total purification in a completely sealed apparatus, without interruption of other process operations.

A further object of the continuous multi-stage metallurgical apparatus invention is to provide means for carrying out a unique but concise method for alloying metals, tending to produce metals and alloys with improved physical and mechanical properties, exacting consistency and total homogeneity.

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A still further object of the continuous apparatus invention is to provide novel means for preheating constituent alloying elements under vacuum and inert gas to surface degasify same before introducing them into the molten pool.

Another object of the invention is to provide continuous multi-stage apparatus having means to accomplish grain refinement by superheating the melt, introducing inert gas at the bottom of the crucible, causing bubbling action, which brings about total homogeneity of the melt, without interruption of the continuity of the process operations.

A further object of the invention is to provide continuous multi-stage apparatus having pouring means that will remain sealed while the molten metal is cast and which will remain sealed after removal of the mold from its position, therefor protecting the cast part, as well as the apparatus, without interruption of the process operations.

A further object of the continuous multi-stage apparatus invention is the provision of discharge conduits and valves, connected to waste molds for discharging contaminant or residues as well as being capable of discharging entire melt in case of accident or necessity to change to other metal, or to evacuate zones, without interruption of process operations.

A still further object of the continuous multi-stage apparatus invention is to provide means for transferring molten metal from one zone to another and means for absolute control of molten metal transfer, without interruption of any zone operation.

A still further object of the continuous multi-stage apparatus invention is to provide means associated with the purifying crucible and alloying crucible to keep purifying and alloying chambers separated from the melting chamber and to exclude atmospheric contaminants when operation of process is in progress without interruption of the operations.

Other and further objects and advantages of this invention will become evident from a consideration of the following specification when read in conjunction with the annexed drawing, in which:

FIG. 1 is an elevational view of a continuous metallurgical apparatus illustrating the principles of the invention and showing an overall system including a charging section, melting crucible, purifying crucible, alloying crucible, pouring system and auxiliary equipment;

FIG. 2 is an enlarged fragmentary view, partially in section, illustrating the charging section of the apparatus of FIG. 1;

FIG. 3 is a cross-sectional view, taken substantially on the horizontal plane of line 3—3 of FIG. 2, looking in the direction of the arrows, and illustrating in greater detail the charging mechanism;

FIG. 4 is a vertical cross-section view taken substantially on the vertical plane of line 4—4 of FIG. 2, looking in the direction of the arrows, and illustrating pivot means for the charging chamber and its associated component parts;

FIG. 5 is an enlarged cross-sectional view taken substantially on the vertical plane of line 5—5 of FIG. 2, looking in the direction of the arrows, and illustrating quick, detachable clamping means for connecting the charging chamber to the external end of a preheating chamber for the melting crucible, the detachable connecting means being illustrated in dotted lines in its open or released position;

FIG. 6 is a vertical cross-sectional view of the first or melting crucible, illustrating the component parts thereof in detail as well as of associated equipment pertinent thereto;

FIG. 7 is a vertical cross-sectional view of the second or purifying crucible illustrating the component parts thereof in detail as well as of associated equipment pertinent thereto, including the means for pretreating and

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adding scavenging elements to the crucible and for withdrawing and condensing volatile impurities;

FIG. 7A is an enlarged vertical fragmentary cross-sectional view of the top of the second or purifying crucible shown in FIG. 7 showing in greater detail the means for preheating and adding scavenging elements and for withdrawing and condensing volatile impurities;

FIG. 8 is a vertical cross-sectional view of the third or alloying crucible illustrating the component parts thereof in detail as well as of associated equipment pertinent thereto, including the means for pretreating and adding alloying elements to said crucible;

FIG. 9 is an isometric view of the sampling and transfer valve utilized in the discharge conduits from the crucibles of the apparatus;

FIG. 10 is a cross-sectional view taken on lines 10—10 of FIG. 9;

FIG. 11 is a cross-sectional view taken on the lines 11—11 of FIG. 9;

FIG. 12 is a cross-sectional view taken on the lines 12—12 of FIG. 9;

FIG. 13 is a vertical-sectional view taken on the lines 13—13 of FIG. 7A;

FIG. 14 is an exploded view in isometric projection showing the components of a seal-tight gate valve utilized in the portion of the apparatus shown in FIG. 7A;

FIG. 15 is a diagrammatic elevational view similar to FIG. 1 but omitting detail and being partially cut away to show the flow of metal throughout the closed system.

The apparatus of the invention, as may be seen from the drawings, particularly FIGS. 1 and 15, comprises a closed, continuous system providing sequential treating zones or stages completely sealed from the atmosphere and provided with means whereby in each stage of the system the metal is continuously subjected either to vacuum, inert gas or combinations thereof. Inert gas, introduced in a novel manner, is utilized for the purpose of excluding atmospheric contaminants, protecting the refractories, stirring the melt to insure homogeneity, and for facilitating transfer of molten metal from one zone to another. The apparatus is provided with means for introducing inert gas into the bottom of the treating zones to cause such gas to permeate the molten metal and drive the impurities to the surface, such impurities being removed from said surface by the simultaneous application of a vacuum above such surface. Inert gas so introduced may also be used to stir the metal and insure homogeneity. Means are further provided for selectively introducing and withdrawing gases from the top of the treating zones to provide a pressure differential to facilitate rapid flow of the molten metal from one zone to another. Vacuum and inert gas means are provided for the pretreatment of the apparatus during stabilization of the refractories to flush impurities therefrom. Vacuum means are also provided for the surface degasifying of the materials added to the apparatus. In the purifying stage of the operation, means are provided for the application of a vacuum for drawing off volatile impurities followed by the application of an inert gas pressure above the surface of the melt to effect rapid settling of precipitated impurities from such melt.

Referring now to the drawings and especially to FIG. 1, a closed system illustrating the invention is shown to comprise a charging section A, a melting crucible B, a purifying crucible C, an alloying crucible D, sampling and transferring valves E, and pouring units F. The purifying crucible C has a special top section G for the addition of and pretreatment of scavenging elements and for the removal of volatile impurities. The alloying crucible D has a special top section H for the addition of and pretreatment of alloying constituents. Inert gas, such as argon or helium, is supplied from a tank 10, where it is stored under high pressure, through an expansion valve 11, purifier 12, and preheater 14 to the base of each crucible, the supply of gas being controlled by valves

15, which are operated automatically or manually in response to pressure indicated by gauges 16. Inert gas is also supplied to the top of each crucible through valved conduits 17. Vacuum may be applied to the top of each crucible by means of vacuum line 18 and valves 19, which also are controlled in response to pressure indicated by gauge 16. Each pouring unit F is also connected to the sources of inert gas and vacuum as shown.

While the exact structure of the crucibles is subject to many changes without departing from the inventive concept of the interconnected closed multi-stage system, one suitable crucible structure will be described in detail below.

The melting crucible

The melting crucible B, shown in detail in FIG. 6, comprises an outer shell including an elongated, substantially hollow, cylindrical side wall 22 having a circular base plate 24 and an open end oppositely disposed with respect to the latter. The outer shell may be formed of low carbon steel, aluminum or copper. The side wall 22 adjacent its upper end, is formed with an aperture 26 for a charging inlet, and below adjacent the base plate 24, is provided a second aperture 28 for a drain outlet. Substantially diametrically opposed to the drain aperture 28, the side wall 22 has another discharge aperture 30 with the center point of the latter being higher than the center point of the former. To prevent eddy currents and inadvertent or accidental arcing between induction heating means (to be described below) and the side wall 22 and its associated base plate 24, the wall 22 and base 24, if made of steel, are provided with a thin coating of lead paint (not shown), or may be provided with an interior copper laminate.

Interiorly of the outer shell and co-extensive with the side wall 22 and base plate 24 is a liner 32 formed of asbestos material. Additional insulating layers inwardly from the asbestos liner 32 comprise diatomaceous material 34, a hollow tubular shell 36 of formed alumina, a layer of granulated alumina 38, a sleeve or shell of mica 40, and a layer of granulated zirconia 42. Next to the granulated zirconia is a sheath 44 of molybdenum or other conductive material, the upper end of the latter terminating in a horizontal plane containing a line passing through the center point of the aperture 26. From that point upwardly is provided a substantially cylindrical shell 46 formed of alumina material. An inner lining 48 is of a special refractory material, preferably composed of a mixture of thoria, zirconia, hafnia, and yttria. The molybdenum sheath 44 around the refractory liner 48 has the dual purpose of (1) serving as a heat-conducting medium for the initial heating of the crucible refractory and (2) as a shield in case of refractory failure.

At the base of the crucible B supported by diatomaceous material 34 is a circular disc 52 formed of alumina having an upright, centrally disposed, conically shaped boss 54 provided with an axial bore 56. Superimposed over the disc 52 is a second disc 58 constructed of formed alumina and having a dome 60 nesting or telescoping over the boss 54. The dome 60 is constructed with a bore 62 coaxially aligned with the bore 56. The lower ends of the alumina shell 36 and granulated alumina 38 are supported on the disc 58 and circumferentially embrace a cover member 64 formed of alumina and having an upright circumferential flange 66 and a second flange 68 disposed inwardly thereof and concentric therewith. A circular mica shield 70 is supported on the flanges 66 and 68, and the space between the shield 70 and cover member 64 is filled with granulated alumina 72. The lower end of the zirconia layer 42 terminates in a domed, circular base 74 which, in turn, supports domed bottom portion 76 of the molybdenum sheath 44. The special refractory liner 48 is formed with an integral base 78, which is also dome-shaped in configuration.

Imbedded in the cover 64 is a hollow tubular induction heating coil 79 having a "beehive" configuration, the ends

80 of which are connected with a source of cooling and conducting liquid, e.g., water, under pressure and with a source of high-frequency, alternating current through leads 81. Tubular induction heating means 79a are similarly provided in the side walls, as in lining 42.

The crucible B adjacent its upper end, receives through the aperture 26 and through the outermost heat insulators referred to above, a cylindrical conduit 82 formed of titanium or other metal to be treated in the system, which opens at its inner end into the special refractory 28, while the other end thereof abuts against a zirconia sealing ring 83 supported in the open end of a steel connector sleeve 84. Surrounding the conduit 82 is a sleeve 86 formed of alumina and in which is imbedded a helicoidal electrical resistance element 88 having terminal ends 90 and 92 connected with a source of electricity. The space 94 within the titanium conduit 82 will hereinafter be referred to as the "pre-heat chamber." Conduit 82 is perforated around its outer end, as at 96, to permit inert gas to be passed over a charge in preheat chamber 94 from manifold 97 and inlet tube 98. The electrical resistance element 88 is constructed in such manner as to provide temperatures up to 2000° F. in chamber 94.

To the exterior end of the connector sleeve 84 is joined a valve casing 102 formed of steel and having a gate valve 104 constructed of steel mounted for reciprocation therein and manually operable by wheel 105. A modified type of valve suitable for use at this point is disclosed in copending application Serial No. 863,289, filed December 31, 1959.

The lower discharge aperture 28 of the steel shell receives therethrough a hollow, cylindrical, open-ended insert 106 of said special refractory material. The insert extends through the above-mentioned insulating layers and at its inner end opens into melting chamber 107 through an opening in the refractory 48. Insert 106 is surrounded by a cylindrical molybdenum sheath 108 and the latter is encircled by a sleeve 110 formed of alumina and having a hollow, tubular, helicoidal induction heating coil 112 imbedded therein through which water or other conducting and cooling liquid is adapted to be passed. Leads 114 and 116 serve to connect the coil 112 with a suitable source of E.M.F.

An elbow connector 118 is connected to the side wall 22 and has an end thereof physically secured thereto in concentric relation relative to the aperture 28. The elbow connector is provided with an elbow liner 120 formed of alumina, and a substantially hollow, open-ended valve insert 122 formed of the same material is coaxially aligned with the insert 106. As is seen in FIG. 6, the refractory insert 122 joins an arcuately shaped, hollow, tubular refractory liner 124 which is in open communication with the open end of a molten metal discharge tube 126 of special refractory surrounded by a descending section 128 of the liner 120. The latter is, in turn, embraced by a hollow, tubular descending section 130 of the connector 118. The insert 122 contains for reciprocation therethrough a valve-plug 132 formed of said special refractory material and controlled by wheel 134. When the plug 132 is retracted as shown, a continuous discharge passage 135 is provided from the lowermost portion of the melting chamber 107. The waste or residue discharge passage 135 is used to empty the melting chamber 107 if it becomes necessary. When the plug 132 is closed, the molten metal in the chamber 107 can contact only the special refractory material.

In receiving relation to discharge passage 135 is an ingot mold 136 having an outer shell 138 of metal or other suitable material. The mold 136 is provided with an alumina liner 140 and an inner hollow body 142 formed of stainless steel having a refractory liner 144, which may be formed by spraying the inside of the stainless steel body with said special refractory material. The upper end of the inner body 142 is connected to a cap 146 having an inert gas admission passage 148 formed therein and a pas-

sage 150 connected with the vacuum source (FIG. 1). The cap 146 receives the lower end of a valve housing 152 having a gate valve 154 which in closed position extends across the lower end of the tube 126. A heat transfer coil 156 is juxtaposed against the liner 140 for temperature control of the mold. A modified form of mold and valve structure suitable for unit F is disclosed in my copending application Serial No. 843,533, filed September 30, 1959.

Conduits 158, 159 and 160 in the bottom 24 of the outer steel shell of the melting crucible are connected to the source of inert gas under pressure, the conduits communicating with passages 162, 163 and 164 and pores and crevasses in the diatomaceous earth layer 34 for diffusion through the several insulating layers described above and through small openings 166 formed in the sheath 44 to serve a function to be described. The inert gas, which eventually finds its way into the top of chamber 107, is exhausted by means of a series of passages 168 at the top of the crucible, such passages being connected through conduits 170 with the suitable vacuum source.

The discharge aperture 30 of the crucible shell has connected thereto an elongated conduit 182 in which is housed an elongated, hollow, tubular, open-ended insert 184 formed of the special refractory material. Surrounding the insert 184 is a sleeve 186 of molybdenum metal which is backed by granulated alumina 188. Around the alumina layer 188 is an induction heating unit comprising a sleeve 190 of formed alumina having a hollow, tubular, helicoidal induction coil 192 embedded therein. The ends 193 of this coil are connected to a source of high-frequency, alternating current by means of electrical contacts 194. This coil 192, like the other induction heating units, is adapted to receive a cooling and conducting liquid. Between the metal conduit 182 and heating unit 190 are insulating materials as disclosed with reference to the melting crucible. The hollow refractory insert 184 provides a passage 196 which connects the melting chamber 107 of the melting crucible B through the sampling and transfer valve E to the purifying crucible C. The conduit section of the downstream side of the valve E is identical to that just described.

The top of the melting crucible B is closed by means of a cover member 200 of low-carbon steel, copper or aluminum, which is clamped to the ball 22 in sealed relation therewith by means of a series of bolts 202. Within the cover member is an inner liner 204 of the special refractory material backed by formed alumina 206. A gasket 208 of neoprene-impregnated asbestos material is interposed between the refractory liner 204 and the ends of the various insulating layers of the crucible.

The top of the refractory lining 48 is provided with a circumferential groove 210, covered at its top by the inner portion of gasket 208 to provide a gas manifold for inert gas introduced through a passageway 212 in the insulating layers 204 and 206 and gasket 208. Passageway 212 communicates with an inert gas supply line 214 by means of a connector 216 in the steel cover 200. Formed within the refractory liner 48 are a plurality of vertical passageways 218 which have openings 220 near the bottom of the melting chamber 107. The tops of the passageways 218 communicate with the manifold 210 as that inert gas supplied through the line 214 may be introduced into the melt within chamber 107 near the bottom thereof, to permeate and stir such melt.

The cover 200 may contain more than one passage 168 whereby vacuum can be readily applied to the chamber 107 above the top of any molten metal therein. Inert gas can also be applied through the passages 168 so as to increase the pressure above the melt when desired. An opening 226 is provided through the insulating materials and shell at the apex of the cover, and a quartz sight glass 228 is mounted over this opening by means of a flanged sleeve 230 and attached retainer ring 232 so that melting conditions may be observed. Pressure

gauge 16 permits pressure conditions within the crucible to be determined and regulated. If desired, pressure gauge 16 may be substituted by a pressure recording-controller which, through a conventional servo-mechanism (not shown), automatically controls the operation of valves 15 and 19 in the inert gas and vacuum lines, respectively, these valves in this instance being of the automatic type. A temperature recording-controller 238 (having conventional control means, not shown, operable on the induction heating circuit), is also mounted on the cover so that the temperature within the crucible may be exactly set and controlled.

The charging section

The charging section A, as illustrated in detail in FIGS. 2-5, comprises a double-acting hydraulic cylinder 310 attached to a housing 312 for a charging sleeve 314, which provides a charging chamber 316. The housing 312, in one position as shown in solid lines in FIG. 2, is adapted to be connected in sealed relation to a flange 318 of the valve 102 defining the entrance to preheating chamber 94 within the walls of the melting crucible A. An air-tight seal between valve flange 318 and housing 312 is effected by means of an O-ring 322 and quick-acting clamp 324. The housing 312 and hydraulic cylinder 310 are mounted upon a carriage 326, which is provided with rollers 328 receivable within tracks 330 so that the charging section can be rolled back as a unit from the melting crucible B when valve 102 is closed and the quick-acting clamp 324 is disengaged.

Track 330 extends downwardly at its rear portion 332 so that as the carriage 326 moves rearwardly the housing 310 can be tipped up, as shown in dotted lines in FIG. 2. In this position, the chamber 316 is ready to receive a charge of the metal to be processed.

The sleeve 314 has a piston ram 334 mounted for movement therein by means of piston rod 336. In the charge-receiving position, the sleeve 314 is retracted within its housing 312 and the ram 334 is in its fully retracted position. In this position, the metal to be processed can be loaded into the sleeve 314 so as to fill or partially fill chamber 316. When the chamber 316 is filled to the desired extent, the entire hydraulic system and housing 312 are brought forward and locked to the valve flange 318 by means of the quick-acting clamp 324, the O-ring 322 between the flange faces forming a vacuum-tight seal between the two sections.

The sliding valve 102 which separates the preheating chamber 94 from the charging mechanism A, is constructed so that when it is closed a vacuum-tight seal is maintained between the chamber 316 and chamber 94. The sleeve 314 and piston 334 of the charging mechanism, as well as the liner 82 of the preheating chamber 94, are preferably made of the particular metal to be processed, e.g., titanium, thus avoiding the accidental introduction of other metals by abrasion of the surfaces contacted by the charge, into the melt during the charging operation.

A tube 350 connected to inert gas and vacuum lines through valves 352 and 354 is provided on the charging side of the valve 102, so as to permit inert gas flushing and vacuum degasifying of the charge in chamber 316 when valve 104 is closed and the housing 312 is clamped to flange 318.

A modified form of charging mechanism suitable for the apparatus combination is disclosed in copending U.S. applications Serial Nos. 505,887 and 775,994, aforementioned.

Sampling and transfer valve

The sampling and transfer valve E acts as a stop-off, sampling device and transfer passage for the flow of molten metal between crucibles or between the crucible and the ingot mold for the final product. As shown in FIG. 6 and FIGS. 9-12, the valve E comprises a housing 350 of low-carbon steel provided with flanges 352 and

354 adapted to be connected in sealed relation with metal conduit sections 182 connecting the various units of the apparatus. Within the housing 350 is a valve cylinder 356 made of the special refractory material, encased within a molybdenum sleeve 358. The cylinder 356 contains a valve piston 360 also of said refractory material machined to fit snugly inside the sleeve 356 and adapted to be reciprocated therein by means of valve stem 362 and wheel 364. The top of the valve is provided with a finned section 366 so that the valve operating mechanism can be prevented from overheating. Inert gas inlets 368 and 369 are provided at the top and bottom of the valve housing and a vacuum outlet 370 is also provided near the top of the housing. A constant inert gas pressure can be maintained within the valve housing to avoid molten metal penetration of the parts.

The valve cylinder 356 and molybdenum sleeve 358 are provided with openings 372, which register with the openings in the inner liner of the connected conduit sections. The valve piston 360 is provided with a passageway 374 having an opening at one end of the same dimension as the opening 372 in the valve cylinder, and an opening 376 in the other end of reduced dimension. The valve stem 362 is provided with a lever 378 whereby in the lowermost position of the valve piston 360 the valve stem and piston can be rotated through a 90-degree angle. When the valve piston 360 is in its upper position, the passageway 374 is in alignment with the opening 372 in the valve sleeve and can receive molten metal from an adjacent crucible. The filled passageway 374 provides a sample slug of molten metal. The piston 360 is then lowered to the position shown in FIG. 10 and the sample slug is allowed to cool. When the sample slug has solidified and cooled to about 1200° F., it is ejected through a door 379 into a vacuum chamber 380 by retracting door screw 382 and advancing an ejector bolt 384. The door 379 is then closed, the ejector bolt 384 retracted and the valve piston 360 rotated by means of lever 378 so that it can be moved by the action of wheel 364 on valve stem 362 to its upper position for either receiving another sample or for permitting transfer of molten metal from one apparatus unit to the other. The sample slug, indicated at 388, deposited in the vacuum chamber 380 is further cooled while vacuum is applied by means of vacuum line 392 and then removed from this chamber through another sealed door 390 for analysis. This method of sampling molten metals permits a quick analysis to be made of the chemical condition of the melt and enables the attainment of a high degree of uniform consistency control.

Another form of transfer valve suitable for the system of the invention is described in my copending applications Serial Nos. 505,887 and 775,994. It will be understood that the sampling means may be eliminated and other valving means utilized without departing from the broad inventive aspects of the continuous closed system.

Purifying crucible

The purifying crucible C is constructed in a similar manner to the melting crucible B previously described except for the top section G, which is shown in detail in FIG. 7A, and with the further difference that the discharge passage 196 from the preceding crucible B takes the place of charging chamber 94. The capacity of the purifying crucible, however, is preferably about one-half the capacity of the melting crucible, so that the melting crucible retains a substantial body of melt even after molten metal has been withdrawn to fill the purifying crucible. The ingot mold outlet F, transfer conduit and sampling and transfer valve system are identical to that just described. Suitable pressure gauges and temperature recording and control means are provided. For convenience the crucible parts of crucible C, which are similar to those of crucible B, are given the same reference numerals.

The top section G of the purifying crucible C provides a combined condensing and scavenger preheating section. In place of the flanged sleeve 230 at the top of the melting crucible, the purifying crucible C is provided with a valve and condenser housing 400 of low-carbon steel provided with a dome-shaped cover 402, the top of which is connected to a vacuum line 404. Cover 402 is held in sealed relation to housing 400 by means of U-bolts 405 and wing nuts 406. Disposed within the bottom portion of the housing 400 is a tubular liner 408 of the special refractory material.

The valve section of this unit is of a special rising-stem gate valve type having sealing and locking means. It comprises top-and-bottom steel plates 410 and 412 held in place within the housing 400 by means of tongues 414 and grooves 416, and by an end plate 418. Intermediate the plates 410 and 412 is a split sliding valve element 419 having an upper section 420 and lower section 422 designed to slide together to open-and-closed positions of the valve. A downwardly directed cylindrical projection 423 in the top section which fits in opening 424 in the bottom section prevents longitudinal and lateral shifting of the sections with respect to each other but permits vertical separation. This extension also functions to prevent passage of vapors outwardly between the two valve sections. An opening 425 is provided in valve section 420 and projection 423, which in the retracted or open position of the valve as shown in FIG. 7, registers with openings 426 in the plates 410 and 412. A wheel working upon a threaded hollow valve stem 420 is utilized to advance and retract the valve sections. The valve sections 420 and 422 may be spread apart and tightly locked in position against steel plates 410 and 412 by means of cams 432 operated by a shaft 434 within the hollow valve stem and connected to lever 436. Thus, in the closed position of the valve (as shown in FIG. 8, with a similar type of valve used in top section H), the purifying crucible can be tightly sealed by means of the lower section 422 of the valve being forced against its plate while the chamber above the valve is sealed by top section 420 being forced against the upper plate.

The upper portion of the housing 400 contains an outer sleeve 438 which rests upon upper plate 412. At the bottom of this sleeve is placed an annular insert 440 upon which a cooling coil 442 rests. The cooling coil is spirally wound around the sleeve 438 and is adapted to receive cooling fluid from a source not shown. Within the sleeve 438 is a condenser sleeve 444 upon which volatile impurities from the purifying crucible are adapted to be condensed during the scavenging operation later described. The top of sleeve 444 is attached to a circular disc 446 which is clamped between the housing 400 and cover 402, O-rings 448 being provided at this point to secure a vacuum-tight seal. A screen 450 covers the top of the sleeve 444 and is held in place by means of bolts 452 which also secure a handle 454 to the condenser sleeve assembly. When the cover 402 is removed from the housing 400, the condenser sleeve 444, screen 450 and disc 446 are readily removed by a vertically upward pull upon the handle 454.

The top plate 412 is provided with an electrical resistance heating unit 456 adapted to be attached to a source of electricity by means of leads 458. When the valve sections are closed, as shown in the analogous structure in FIG. 8, cover 402 may be opened, condenser sleeve unit withdrawn and a cartridge of scavenger elements (shown in dotted lines at 460) disposed upon the upper surface of valve section 420. The condenser sleeve and cover are then re-assembled. The cartridge of scavenging elements resting upon the upper valve section 420 is heated by means of coil 456 to a suitable temperature, for example, around 1200–1500° F., while a vacuum is being pulled through line 404. In this manner, scavenging elements are surface-degasified prior to the time they are introduced into the melting and purifying

furnace. The cartridge 460 is dropped into the purifying crucible by unlocking and withdrawing the valve to the position shown in FIG. 7. The interior of the housing 400 may be placed under inert gas pressure through valved conduit 462.

The valve structure at the top of the purifying crucible alternatively may be of the structure disclosed in my copending application Serial No. 863,289, filed January 31, 1959.

The alloying crucible

The alloying crucible D is identical to the purifying crucible C except for the top section H. This top section, as shown in FIG. 8, differs from the top section G of the purifying crucible in that no condenser means need be provided. Thus, a housing 468 is provided which accommodates a split, seal-tight gate valve 470 which is identical to that shown in FIG. 7, except that the top plate does not contain a heating unit. The housing 468 in the top section H is provided with a resistance heating unit 472 which comprises resistance wire coil 474 embedded in an alumina form. A cover member 476 is provided for the housing 468 and is formed integrally with a section of conduit 478 which provides an alloy preheating and degasifying chamber 480. A cartridge 482 of alloying constituents is shown in place upon the top surface of the sealed gate valve in the chamber 480. A closure member 484 is provided for the top of the conduit 478. This closure member is, in turn, connected to the source of vacuum through flexible vacuum line 486. Closure member 484 may be readily removed by releasing swinging bolts 488 so as to provide access to the chamber 480. It will be understood that suitable gaskets are provided so as to ensure sealing relationship between the various closure members. The interior of the housing 468 may be placed under inert gas pressure through valved conduit 490. The resistance heating element 472 is of such design as to provide temperatures up to 1800–2000° F. within the alloying chamber 480.

For convenience, the parts of the crucible D that are similar to those of crucibles B and C are given the same reference numerals.

It will be understood that in the operation of the process and apparatus as previously described, suitable auxiliary equipment may include induction units of the motor generator type (rated, for example, at 30 to 50 kw.), additional vacuum pumps, coolant supply lines and pumps, pressure regulating and reduction valves, temperature measuring, control and recording instruments, and analytical equipment necessary for the determination of sample specification.

Each unit of the apparatus is separately controlled as to vacuum, inert gas pressures and temperatures. The process steps, however, in the overall operation are interrelated and cooperate to provide a uniform product with a high degree of accuracy and quality control. The prepurified and preheated inert atmosphere for flushing the apparatus is vacuumed and replenished at regular intervals, and this plus the constant temperatures retained throughout the entire system tends to keep the refractories in a state of stability and neutrality, thereby providing for long life and low maintenance cost.

Principles of operation

In describing the operation of the continuous vacuum and inert gas process and apparatus, the description will relate to five main steps, namely, (1) charging and preheating, (2) melting, (3) purifying, (4) alloying, and (5) pouring.

Although this process lends itself for the treatment of all the conventional metals, it can be used with special advantage for the reactive metals (refractory metals) with the same degree of improvement in quality and consistent homogeneity. Titanium will be used to describe the operation of the process and apparatus.

Charging operation.—With the vacuum and inert gas valves 352 and 354 in the closed position and the gate valve 102 separating the preheating chamber 94 from the charging chamber 316 completely closed and sealed, the charging section housing 312 is drawn back to the position shown in dot-dash lines in FIG. 2 and fine titanium scraps or small pieces of titanium sponge are loaded into the cylinder 314. The housing 312 is then locked against the flange of the preheating chamber and locked tightly by clamp 324. The vacuum of the charging section is turned on by opening valve 354. The vacuum applied may range from 10^{-2} to 10^{-4} mm. Hg. The charge may further be completely flushed of atmospheric contaminants by alternately admitting inert gas and then applying vacuum by manipulation of valves 352 and 354.

The gate valve 102 is then opened and the charged titanium placed in the preheating chamber 94 by the hydraulic system, the cylinder 314 and ram 334 being advanced together into the chamber 94, also as shown in dot-dash lines in FIG. 2, and the cylinder 314 then being retracted hydraulically while the ram remains stationary to thereby deposit the charge gently in preheat chamber 94 without contact with the elements of valve 102. After the cylinder 314 and piston ram 334 have returned to their original position, the gate valve 102 is closed and the material preheated in chamber 94 by the resistance coil 88 to about 1900° F. or 2000° F. During the operation inert gas is admitted cyclically to chamber 94 through line 98 while vacuum is drawn at the top of crucible B through line 170 and valve 19. In the presence of the controlled atmosphere, at these temperatures the charged titanium is surface degasified. A repeated operation follows, and the first charge is injected into the melting crucible. Thus, by repeating the charging, the molten titanium in the crucible reaches its full capacity while the inert gas and the vacuum valves are manipulated to provide cycling between a high of 12 to 15 p.s.i.g. and a low of 2 to 3 p.s.i.g. as has previously been described, thereby flushing the apparatus and materials and removing flushing gases.

Melting.—The charging is then stopped and melting is completed. During the melting operation, in which crucible B is heated to about 3270° F., the molten titanium is permeated with inert gas which, for example, may be argon or helium, this inert gas having been prepurified, preheated and pre-expanded, as has been described previously. The inert gas used in the permeation is introduced through openings 220 in the crucible at a pressure causing permeation through the melt, thereby causing the release of gas contaminants which are brought to the surface of the melt and exhausted by the vacuum.

A sample of molten titanium is taken by the sampling and transfer valve E in the form of a cylindrical slug by the following application: The inert gas permeating through the melt is completely closed by closing the valve in line 214. The inert gas valve located in line 170 in the cover and directly over the melt is now opened (vacuum valve 19 being closed), creating a continuous increase in pressure in melting crucible B while the purifying chamber pressure is now reduced to two-pound gauge by appropriate valve manipulation.

The sampling valve piston 360 is now rotated and raised to the sampling position, shown in dot-dash lines in FIG. 6, so that a minute break-through is noticed from crucible B to crucible C, relieving conduit pressure. The molten metal will fully occupy the cylindrical sample space to form the sample slug with substantially no transfer of molten metal to crucible C. The piston 360 is lowered carrying the slug, while the passage between the crucibles is now fully closed.

After the sample slug has solidified and cooled off to about 1800° F. while in an atmosphere of inert gas admitted through line 369, it is ejected into the vacuum chamber 380, as previously described. It is then fur-

ther cooled while subjected to vacuum and then removed and analyzed. Then the valve piston 360 is raised to the transferring position, the opening 376 in this case being in full alignment with the conduit opening to the purifying crucible.

Pressure (e.g. 12 p.s.i.g.) applied from the melting chamber expedites the transferring of the melt into the purifying chamber which may be at about 2 p.s.i.g., as previously indicated, while a rapid analysis is made of the slug to determine the chemical composition of the metal to be purified. When this is accomplished, the appropriate scavenger elements in proper quantities are placed in a titanium cartridge and made ready to be placed in the scavenger chamber shown in FIG. 7 and previously described. Only a part of the molten titanium is transferred, but its quantity is controlled by filling crucible C to a predetermined height as checked by sight glass or other appropriate means. The volume at this height has been predetermined. Since the melting chamber capacity is twice the capacity of the purifying chamber and only part of the molten titanium is transferred, all charges introduced in the melting chamber fall into a molten titanium bath, which highly expedites the melting and protects the bottom of the crucible from damage by impact.

Purifying.—The cartridge 460 (FIG. 7) carrying the scavenger elements is placed in the chamber above the melt, the sliding valve 419 holding the cartridge while the resistance coil 456 heats the cartridge and the vacuum drawn through line 404 evacuates the scavenger chamber. The cartridge is heated to about 1100° F. while the vacuum is in the order of 10^{-2} mm. Hg, accomplishing degasification of the scavenger elements. At these temperatures, the scavenger cartridge 460 is released into the melt by pulling back the sliding valve 419 while inert gas introduced through openings 220 in crucible C agitates the melt and increases pressure.

The drop of the cartridge and the releasing of the scavenging elements in the melt cause an exothermic reaction, producing further agitation and a temporary, slight increase on temperature in the melt, the crucible temperature being approximately 3100° F. While the titanium cartridge is consumed in the melt, the remaining contaminants combine with the scavenger-sublimating elements picked up by the vacuum drawn through line 404 and are directed through the condensing sleeve 444 where the sublimating vapor elements solidify on the condenser sleeve, which is cooled by passage of cooling fluid through coil 442. The gas contaminants are exhausted into the atmosphere by the vacuum. The following conditions preferably are kept in equilibrium during the purifying and sublimating period:

- (1) Pressure of exhaust (vacuum speeds) sufficient to lower the pressure above the melt to 2 or 3 p.s.i.g.
- (2) Pressure of permeation (inert gas) sufficient to agitate melt and permeate all portions thereof—about 12 to 13 p.s.i.g. at line 214.
- (3) Temperature of purifying chamber close to but slightly above the solidifying temperature of the molten titanium at all times — approximately 2100° F. or slightly higher in the initial step.
- (4) Speed of sublimating vapor (controlled by composition used in the scavenging elements), sufficient to complete the sublimation within a period of a few minutes.
- (5) Temperature of condensing sleeve below the solidification point of the volatile metallic impurities—usually in the order of 1000° F.

The sliding valve 419, which separates the condensing chamber from the purifying crucible, is closed and sealed immediately after the scavenging reaction ceases, thus completely shutting off the vacuum. Also, the permeating inert gas in the crucible is shut off and the inert gas valve to line 170 is opened. The inert gas admitted directly over the molten pool is permitted to build up a

pressure over the surface of the melt in the range of 10 to 15 p.s.i.g., the exact pressure within this range depending on the quantity of residual elements in the melt—the greater the quantity of residual elements, the higher the pressure. The inert gas surrounding the crucible also is increased to the same value through lines 158, 159 and 160, establishing a state of pressure equilibrium within the purification crucible.

At this point, all residual elements of alloying elements that are heavier than titanium and are grain-suspended in the molten pool are segregated and rest at the bottom of the crucible. These residual elements may be flushed out into the waste ingot mold immediately, or flushed out after the purified molten titanium has been first transferred into the alloying chamber. A time period of one to two minutes at equilibrium is generally sufficient to effect the segregation and settling of the residual elements. Although in specific examples described herein, mention is made only of titanium, aluminum and magnesium, this method of differential pressure application over other metals in their molten state in the same manner will cause all residual contaminant elements to definitely segregate and rest at the bottom of the crucible, thus effecting a total purification of the melt.

The sampling of the purified melt is carried on in the same manner as has been described in a previous paragraph in the melting section. If the degree of purification is satisfactory, the pure molten metal is then withdrawn as such into an ingot mold, or is transferred to the alloying crucible D by the previously described transfer technique.

Alloying.—When the analysis of the titanium is completed and alloying is desired, the alloying elements selected are then placed in a titanium cartridge and lowered into the alloying preheating chamber 480 of section H (FIGS. 1 and 8) where resistance coils 474 preheat them to about 1800° F. to 2000° F., depending on the alloying elements selected, in the presence of a vacuum of the order of about 10^{-2} to 10^{-4} mm. Hg drawn through line 486. At these temperatures, surface contamination of the alloys is totally reduced. Then the sliding gate valve element sealing the chamber 480 from the crucible chamber and holding the alloying cartridge 482 is opened momentarily, allowing the cartridge to drop into the molten titanium pool where the permeating inert gas introduced through openings 220 agitates the melt.

The temperature of the molten pool is gradually raised to about 3450° F. to accomplish a superheating effect. At this point a minute quantity of sulphur dioxide (SO_2) is introduced into the inert gas, the amount being regulated to the desired grain refinement and may, for example, constitute one or two percent of the permeating gas. Thus, a homogeneous, refined grain alloy is developed. The pressure over the melt in alloying crucible D is maintained in the order of 3 p.s.i.g. by evacuation of the permeating gases through line 170 at the top of the crucible.

Soon after the titanium alloy has become homogeneous, which may require several minutes at the superheat temperature, the inert gas is stopped by shutting the valves and vacuum is continued through line 107, thereby reducing inert gas pressure over the melt to about 2-pound gauge. The melt is then transferred to the preheated, prevacuumed and preflushed ingot mold. Alloys made by this process-apparatus are consistently exact and accurate in chemical composition. If desired, crucible D may be used for grain-refining pure titanium rather than for alloying.

Pouring.—The molten titanium or titanium alloy can be poured directly into an ingot mold, electrode bar mold, billet mold or other desired receptacle. The interior face of the mold illustrated is heavily sprayed with a fine refractory material similar to the special refractory lining used for the crucible. The mold is preheated to about 1000° F., prevacuumed and flushed with inert gas, the

pressure of which is held constant at about 12-pound

gauge while the molten metal is poured. As soon as about one-fourth of the melt is transferred into the mold, cooling air is circulated through the coil 156 of the mold, bringing about uniform solidification of the form. The molds attached to the melting and purifying furnaces work exactly the same as the alloy ingot mold and are used to empty residual materials, to withdraw pure titanium from crucible C, or to empty the molten metal in case of an emergency in any one of the chambers.

The apparatus and its operation thus far described has referred to use of the valve unit E between the crucibles of the multi-crucible system. By proper operation of these valve units the various crucibles can be separately isolated during treating operations therein. Thus, as shown in the diagrammatic illustration of FIG. 15, the first crucible can be filled to capacity by introducing repeated charges of preheated surface-degasified solid metal into the body of molten metal maintained therein while the valve unit E between crucibles B and C is closed. As shown in this figure, the purifying crucible C is completely isolated from crucibles B and D by means of the valve units E. Thus, a purifying operation may be conducted in the crucible C without in any way introducing contaminants into the other two crucibles or interfering with the operations being conducted in such other crucibles. While purification is going on in crucible C and crucible B is being charged, a casting operation can be performed upon the metal in crucible D. As shown in FIG. 15, valve unit E in the discharge conduit from this crucible is open and molten metal from the crucible is being transferred to the ingot mold F. After crucible D has been exhausted by the casting operation the valve unit E in its discharge conduit is closed. The valve unit E between crucible C and D is opened (assuming purification of the molten metal has been completed in crucible C) and another batch of molten metal is transferred to crucible D for alloying or refining purposes. By proper manipulation of valve units E, the purifying crucible C is isolated from alloying crucible D and receives another batch of molten metal from crucible B and so on.

Summary

While it would be possible to conduct an entire purifying, melting and alloying operation in a single crucible of the type described, it is highly preferable from the standpoint of product purity and homogeneity, prolonging the life of the apparatus and providing maximum output capacity to utilize the three-stage apparatus described. Thus, the apparatus is operated in a continuous manner with melting, purification and alloying or refining being conducted substantially simultaneously in the different zones. The first crucible is recharged while purification is proceeding in the second, and the second crucible is replenished while alloying or refining is proceeding in the third. No contaminants or undesired constituents are carried over from one stage to the other, since the stages are conducted in separate, isolated zones. No batch operation has yet achieved the product homogeneity and consistently afforded by the continuous process operated in the manner disclosed.

The maintaining of constant temperatures and the introduction of preheated materials into a molten pool highly increases the production capacity, thus effecting a saving in power consumption. For example, a 50-pound capacity unit operating continuously for 30 days can easily produce about 75,000 pounds of titanium, a feat that cannot be duplicated by any type of apparatus twice its capacity. Furthermore, since this is a compact multi-stage process, its cost of manpower operation is greatly reduced. It is evident that titanium and other metals processed by this method will attain higher physical and mechanical properties with more consistency and homogeneity than can be realized by other methods.

During the entire operation previously described, the crucible refractories are maintained at substantially constant temperature and are flooded with inert gas admit-

ted directly thereto through the bottom of the crucible shell. The pressure of the inert gas so admitted is preferably regulated so as to equalize the gas pressures in the refractories with the pressures within the chambers enclosed by such refractories. It will be seen that this use of inert gas not only prevents contamination from possible leaks to the atmosphere, but prolongs the refractory life.

Vacuum for complete evacuation, designated in the drawings (FIG. 1) as high vacuum and in the order of 10^{-1} to 10^{-4} mm. Hg is applied in the first stage of stabilizing the refractories and thereafter is applied only in the charging chamber A, the scavenger chamber G, the alloying chamber H, the sampling chambers and ingot molds. In the crucibles B, C and D, the pressure varies constantly from a high of about 12-15 p.s.i.g. to a low of about 1-3 p.s.i.g., except in the purifying crucible C during the settling of residual impurities. The vacuum applied to the crucibles through the line 170 is merely for the purpose of purging the crucibles at intervals, thereby providing the pressure reduction to 2 p.s.i.g. The specified high and low pressures are not sharply critical but may be varied as desired, provided a cyclic purging and constant inert gas pressure is maintained.

It will be understood that the foregoing exemplifications of the process are by way of illustration and that the invention is limited only by the scope of the appended claims. In the claims, the word "metal" is also intended to include alloys.

I claim:

1. A continuous apparatus for the melting and treatment of metals, comprising: a series of inter-connected refractory-lined crucibles providing a closed gas-tight system, each of said crucibles in the series excepting the last crucible having a refractory-lined conduit arranged to discharge molten metal into the next crucible of the series and the last crucible having a refractory-lined conduit arranged to discharge molten metal into a mold; heating means for each of said crucibles; means including a refractory valve element in each discharge conduit to selectively seal each crucible so as to maintain a body of molten metal therein during a treating operation; at least the first crucible of said series having feed means for introducing solids into the closed system, said feed means having means for excluding atmospheric contaminants from the closed system and said feed means including a chamber for holding said solids for pretreatment and gas-conduit means connected to said chamber; and each crucible having means for the introduction of treating gases and for withdrawing gases therefrom.

2. The apparatus of claim 1 wherein each of said crucibles, beginning with the first crucible of the series is elevated with respect to the next crucible of the series so that discharge of molten metal from one crucible to the next may be effected at least in part by gravity flow.

3. The apparatus of claim 1 wherein adjacent crucibles are provided with means for establishing a pressure differential therebetween to facilitate transfer of molten metal from one crucible to the next in the series.

4. The apparatus of claim 1 wherein the refractory-lined discharge conduit from one crucible to the next crucible in the series connects the lower part of said one crucible to the upper part of the said next crucible.

5. The apparatus of claim 4 wherein the connecting conduit is provided with temperature control means.

6. The apparatus of claim 5 wherein said temperature control means comprises metal tubing wound around an inner lining of said conduit to provide an induction heating coil, the ends of said tubing being provided with connecting means for a high frequency alternating current, and said tubing being arranged to be connected to a source of cooling and conducting liquid.

7. A continuous apparatus for the melting and treatment of metals, comprising a series of inter-connected refractory-lined crucibles providing a closed system, each

crucible defining a treating zone, the first of said crucibles in the series having a discharge conduit arranged to discharge molten metal into the next crucible of the series and the last crucible of the series having a discharge conduit arranged to discharge molten metal into a mold; means in each discharge conduit for selectively isolating the treating zone of each crucible from the next adjacent zone; at least one of said crucibles having a vacuum feed chamber connected thereto for surface-degasifying and discharging solid materials into said crucible, said vacuum feed chamber having means for preheating said solid materials; at least one of said crucibles having means for introducing inert gas into the molten metal therein and for withdrawing inert gas and vaporized materials therefrom; and the closed system being provided with means for maintaining an inert gas atmosphere throughout.

8. A continuous apparatus for the melting and treatment of metals comprising a series of inter-connected refractory-lined crucibles providing a closed system, each crucible defining a treating zone, the first of said crucibles in the series being arranged to discharge molten metal into the next crucible of the series and the last crucible of the series being arranged to discharge molten metal into an ingot mold, means between each crucible and between the last crucible and the ingot mold for selectively isolating the treating zone of each crucible from adjacent zones, each crucible having a vacuum feed chamber connected thereto for receiving, surface-degasifying and discharging solid material into said crucible, each of said crucibles having means for introducing inert gas into the molten metal therein and for withdrawing inert gas and vaporized materials therefrom, the closed system including the ingot mold being provided with means for maintaining an inert gas atmosphere throughout.

9. The apparatus of claim 8 wherein the system comprises a melting crucible for receiving a charge of surface-degasified metal to be treated, a purifying crucible for receiving molten metal from the melting crucible and an alloying crucible for receiving purified molten metal from the purifying crucible.

10. The apparatus of claim 8 wherein the feed chamber connected with each crucible has means associated therewith for preheating the feed material prior to its introduction into said crucible.

11. The apparatus of claim 8 wherein one of said crucibles defines a purifying zone, the vacuum feed chamber to said crucible provides a means for the introduction of surface-degasified scavenging elements, and said vacuum feed chamber contains a condensing sleeve for condensing vaporized metal withdrawn by vacuum from said crucible during a scavenging reaction.

12. The apparatus of claim 8 wherein one of said crucibles defines an alloying zone, and the vacuum feed chamber to such crucible provides a means for the introduction of surface-degasified alloying elements.

13. The apparatus of claim 8 wherein each of said crucibles is provided with induction heating means.

14. The apparatus of claim 7 wherein the refractory material lining said crucibles is perforated and means are provided to supply said material with an inert flushing gas.

15. An integral, inter-connected multi-stage continuous apparatus for the melting, purifying, alloying and casting of metals, comprising means defining: a charging section, a melting crucible arranged to receive charges of metal from said charging section, a purifying crucible arranged to receive molten metal from said melting chamber, an alloying crucible arranged to receive molten metal from said purifying crucible, and an ingot mold arranged to receive molten metal from said alloying crucible; each of said crucibles and said ingot mold and the connections therebetween being refractory-lined; said crucibles having induction heating means within the refractory linings and said ingot mold having heating means for temperature control; said charging section, each of said crucibles and

said ingot mold having means for supplying inert gas thereto; means for evacuating gases from each of said crucibles and from said charging section and ingot mold; said means defining the charging section including a vacuum chamber and a preheat chamber and means for transferring a charge of metal through said vacuum chamber and preheat chamber into said melting chamber; means between each of said crucibles and between the alloying crucible and ingot mold for selectively stopping the flow of molten metal so as to maintain a body of molten metal in said crucibles during a treating operation therein; said purifying crucible having a vacuum feed chamber for introducing scavenging elements; and said alloying crucible having a vacuum feed chamber for introducing alloying elements.

16. The apparatus of claim 15 wherein the preheat chamber of the charging section is disposed at least partially within the refractory lining of the melting crucible.

17. The apparatus of claim 15 wherein the melting crucible is of a substantially greater capacity than that of either of the other crucibles.

18. The apparatus of claim 15 wherein the means for supplying inert gas to the crucibles includes means within the crucible linings to supply inert gas into the crucible chamber near the bottom thereof, and wherein at least the purifying crucible is provided with means for supplying inert gas near the top of the crucible.

19. A continuous apparatus for the melting, purifying and alloying of metals, comprising: a melting crucible, a purifying crucible and an alloying crucible inter-connected to provide a closed continuous system, the melting crucible being arranged to discharge molten metal into the purifying crucible, the purifying crucible being arranged to discharge molten metal into the alloying crucible and the alloying crucible being arranged to discharge molten metal for casting, means for selectively sealing each crucible to provide a closed isolated zone therein during a treating stage, each of said crucibles having a feed chamber connected thereto for discharging solid material into said crucibles, means for heating said feed chambers to thereby preheat said solid materials prior to their introduction into a respective crucible, means for supplying inert gas to said feed chambers and to selectively apply a vacuum thereto to remove atmospheric contaminants and surface degasify said solid materials, each of said crucibles having means for introducing inert gas into the molten metal therein and means for withdrawing gases and vaporized substances therefrom, and the closed crucible system being provided with means for maintaining inert gas pressure therethrough without interruption of the process operations in the system.

20. The apparatus of claim 19 wherein the alloying crucible is provided with a valved discharge conduit and an associated ingot mold whereby alloyed metal may be cast into said mold, and wherein the melting and purifying crucibles are each provided with valved discharge conduits and associated molds for selectively withdrawing waste material or for emptying said melting and purifying crucibles.

21. The apparatus of claim 19 wherein the purifying crucible is provided with means for introducing inert gas under superatmospheric pressure into the upper region of the crucible to cause the molten metal in said crucible to settle under pressure and contaminants to segregate at the bottom of the crucible.

22. The apparatus of claim 19 wherein the feed chambers connected to the purifying and alloying crucibles are mounted on said crucibles above the respective crucible chambers, each feed chamber is provided with a removable cover, and a valve providing a gas-tight closure is positioned between each feed chamber and the underlying respective crucible chamber whereby the scavenging and alloying elements to be added to the respective crucibles

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may be preheated and surface degasified in the feed chambers without interruption of other processing operations in the crucibles.

23. The apparatus of claim 19 wherein the discharge means from one crucible to the next crucible of the series and from the last crucible for casting comprise refractory-lined conduits, and wherein each said conduit is provided with a sampling and transfer valve, said valve sequentially operating to close said conduit, withdraw a sample of molten metal from said conduit, and open said conduit for transfer of molten metal therethrough.

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