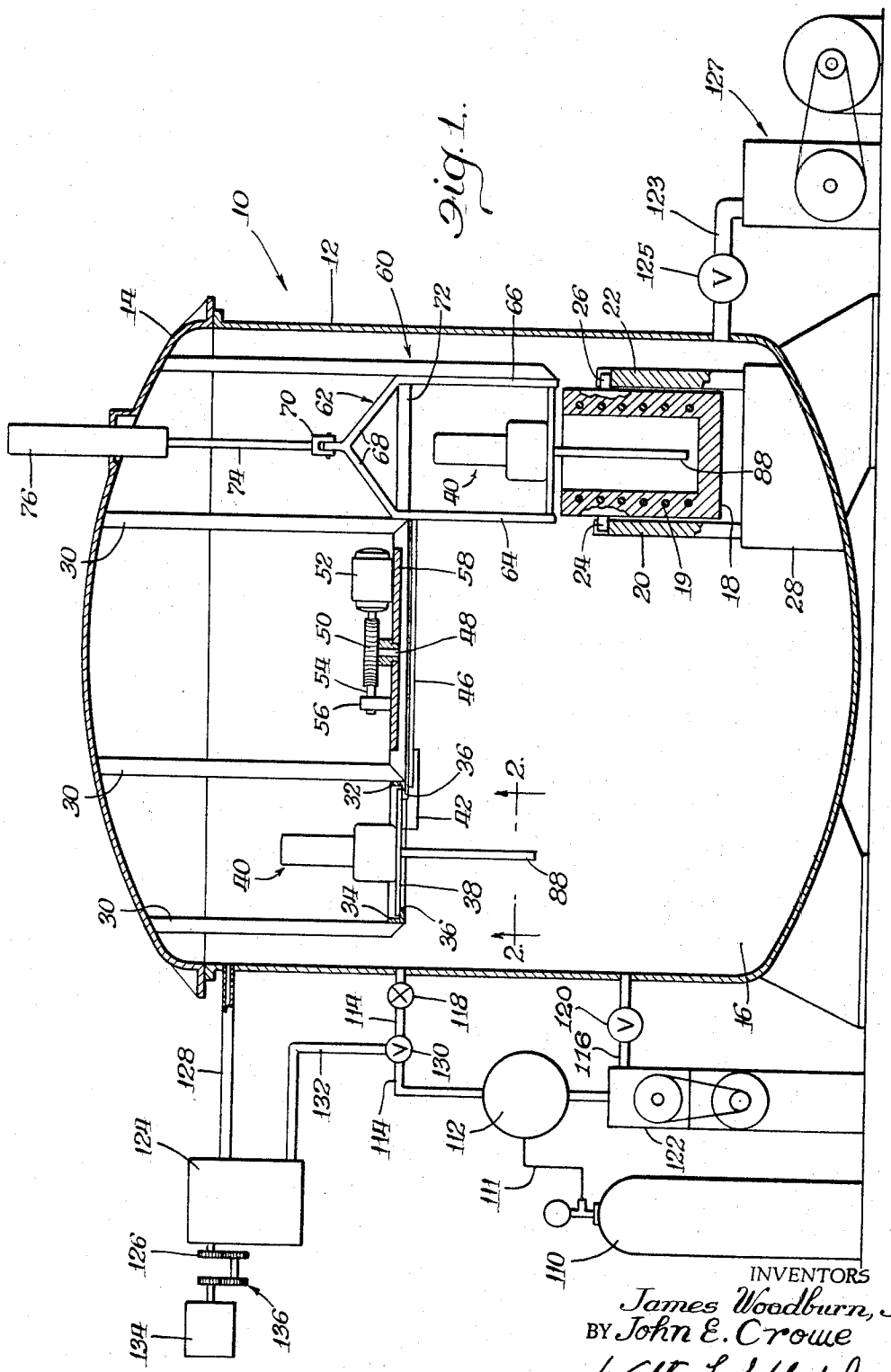
Nov. 12, 1968 J. WOODBURN, JR., ET AL 3,410,332

METHOD AND APPARATUS FOR CASTING METALS IN A CONTROLLED ATMOSPHERE

Filed June 7, 1965 4 Sheets-Sheet 1

Fig. 1.



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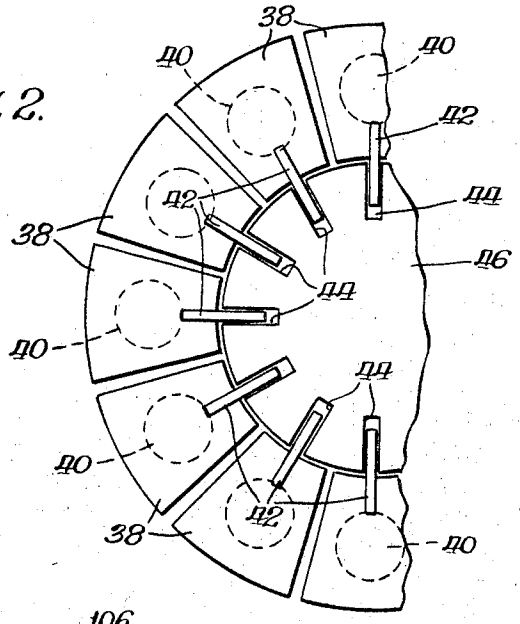
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METHOD AND APPARATUS FOR CASTING METALS IN A CONTROLLED ATMOSPHERE

Filed June 7, 1965 4 Sheets-Sheet 2

Fig. 2.



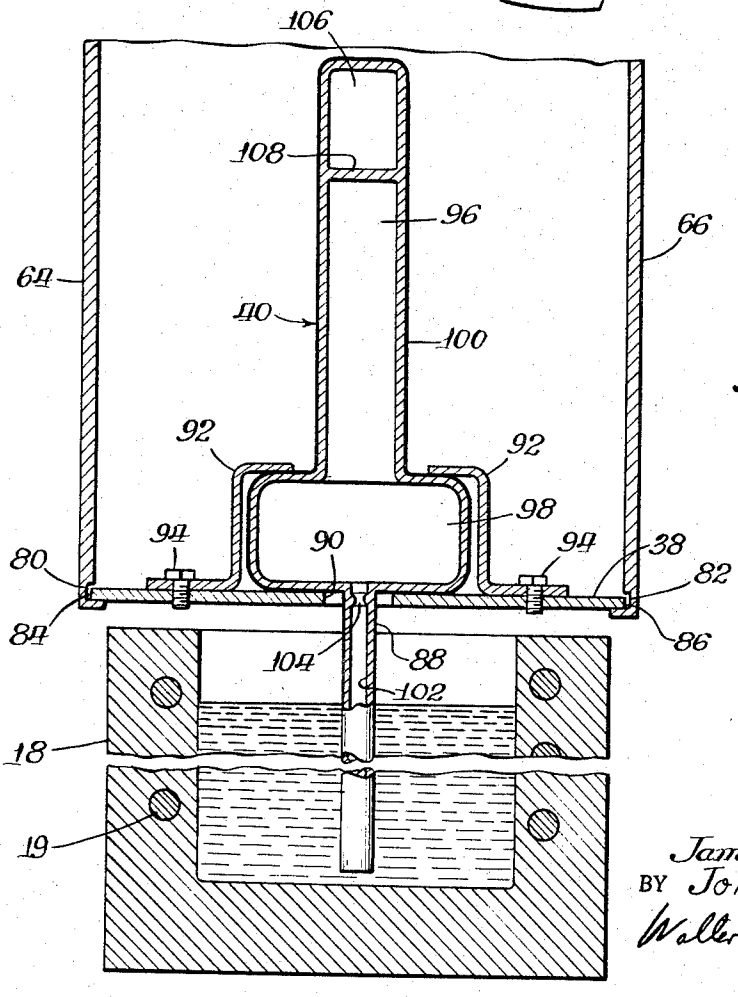


Fig. 3.

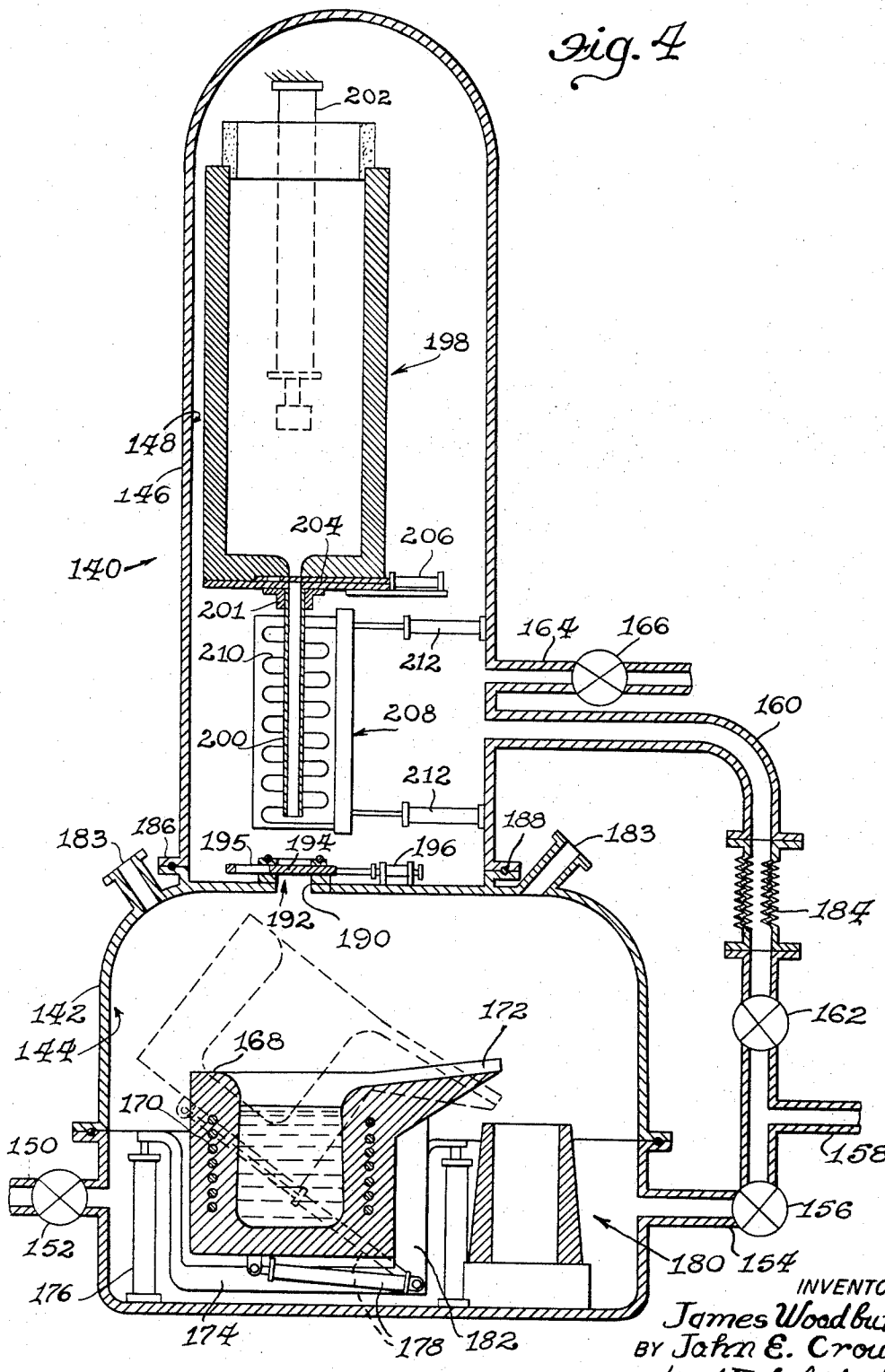
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Nov. 12, 1968 J. WOODBURN, JR., ET AL 3,410,332

METHOD AND APPARATUS FOR CASTING METALS IN A CONTROLLED ATMOSPHERE

Filed June 7, 1965 4 Sheets-Sheet 3

Fig. 4



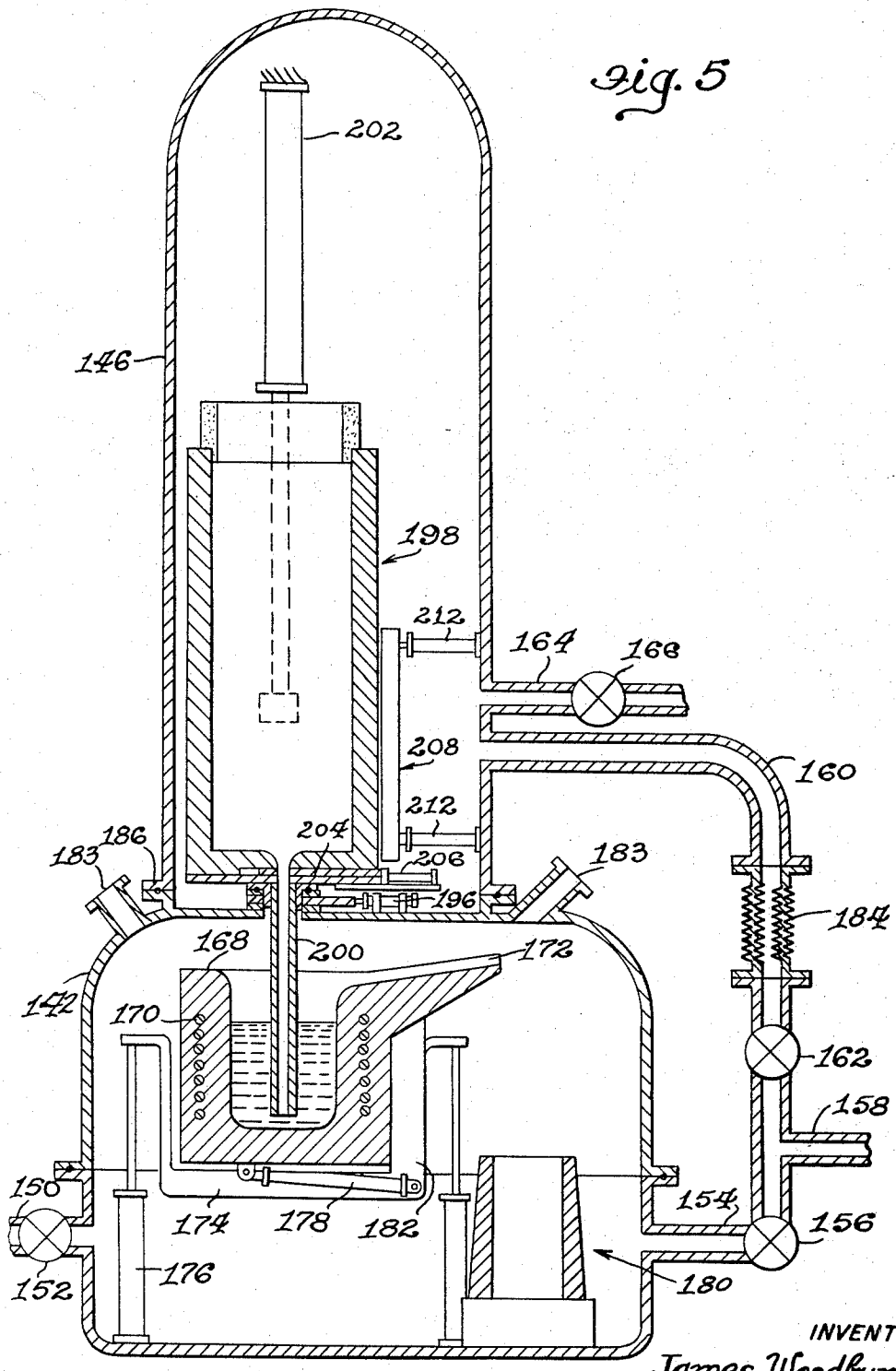
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METHOD AND APPARATUS FOR CASTING METALS IN A CONTROLLED ATMOSPHERE

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Fig. 5



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United States Patent Office 3,410,332 Patented Nov. 12, 1968

3,410,332

METHOD AND APPARATUS FOR CASTING METALS IN A CONTROLLED ATMOSPHERE

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Filed June 7, 1965, Ser. No. 462,001
8 Claims. (Cl. 164—61)

ABSTRACT OF THE DISCLOSURE

In an apparatus for pressure pouring molten metal in a controlled atmosphere, a mold in a gas-tight housing communicates with a ladle in a gas-tight tank. The tank and the housing may be pressurized or evacuated together or separately. A pressure differential is created between the tank and the housing forcing molten metal from the ladle into the mold. The tank may then be sealed and the mold may be removed from the housing while a controlled atmosphere is maintained in the tank.

This invention relates generally to the art of metal casting and more specifically to the art of casting metals which are highly reactive to the ambient atmosphere.

The invention has to do with controlling the atmosphere surrounding the metal in both the melting and pouring operations. As is known, many metals react unfavorably to oxygen, and for eliminating those bad effects, the casting is performed in a controlled atmosphere, such as in an inert gas. As the metal is heated, it progressively so reacts with the oxygen and thus it is desired that the metal be melted in an inert gas, as well as being poured and actually cast in that atmosphere.

A broad object of this invention is to provide a novel method of casting molten metal in a controlled atmosphere.

Another general object is to provide novel apparatus for carrying out the above method.

A more specific object is to provide mold apparatus including a tank sealed against atmosphere with a mold contained entirely therein, and novel means for pressure filling the mold by the use of an inert gas, when in the tank.

A still further object is to provide a novel mold for use in the above apparatus.

In one embodiment of the invention, a tank is provided in which both the ladle and the molds are enclosed, and in which the molds are successively poured in that tank in a period in which no natural atmosphere is present.

In another form of the invention a tank is provided for the ladle, and another tank or housing for the mold, and provision is made for connecting these two containers for the pouring step, and then sealing them off from one another for retaining the ladle in an inert gas atmosphere while enabling the housing containing the mold to be detached and enabling another empty mold to be placed therein for a successive pouring operation.

Another and more specific object, therefore, is to provide novel apparatus for enabling an indefinite number of molds to be filled from a single heat in which the ladle is retained in a controlled atmosphere throughout the pouring of the heat, and the molds are successively placed in a controlled atmosphere during pouring and later removed therefrom.

Other objects and advantages will become apparent when reference is made to the following description and accompanying drawings wherein:

FIGURE 1 is an elevational view, partly in cross-section, of an arrangement for the casting of metals constructed in accordance with the teachings of one embodiment of the invention;

FIGURE 2 is a view taken at line 2—2 of FIGURE 1;

FIGURE 3 is a large side view of a portion of FIGURE 1 at the right hand side thereof, and showing the mold in section;

FIGURE 4 is a vertical sectional view of apparatus made according to a second embodiment of the invention; and

FIGURE 5 is a view similar to FIGURE 4 but with certain of the parts in alternate positions.

Certain details may be omitted from one or more of the figures for purposes of clarity.

First embodiment

Attention is directed first to FIGURES 1–3 which illustrate one embodiment of the broad features of the invention. FIGURE 1 illustrates a casting arrangement including an outer container **10** having a lower body portion **12** and an upper cover member **14** releasably secured thereto in sealing engagement therewith. Any suitable clamping means (not shown) may be provided for so securing the cover **14** to body portion **12**.

In the chamber **16** of container **10** at the lower portion thereof is an induction furnace **18**, serving as a ladle, of suitable and known kind which may be mounted on suitable supports **20** and **22** by means of trunnions **24** and **26**. Supports **20** and **22** may, of course, be secured to a suitable base **28**.

A plurality of downwardly depending support members **30**, secured at their respective upper ends to cover **14**, support a generally arcuate or circular track including inner and outer guide members **32** and **34**, respectively, which have laterally disposed flanges **36**. Flanges **36** in turn serve to support a plurality of individual horizontal pallets **38** each of which carries a mold **40**. The pallets **38** (see FIGURE 2) are generally sector-shaped and together occupy an annular shaped space. Each of said pallets **38** has secured thereto a motion transmitting arm **42** which projects radially inwardly loosely and disconnectedly into a cooperating driving slot **44** formed in a central driving wheel **46** disposed on a vertical axis and mounted on a shaft **48** which is connected at its upper end to a worm wheel **50**. An electric motor **52** is operatively connected to one end of a worm **54** journaled at its other end in bearing block **56**. The entire driving arrangement may be supported on a base plate **58** suitably secured to the depending support members **30**.

It is, of course, conceivable that the arrangement illustrated by FIGURE 1 could contain any number of molds **40**, depending, of course, on the physical limitations of the outer container **10** and the size of the molds. However, for purposes of illustration, it is assumed that the track, defined by guides **32** and **34**, contains eleven molds **40** and pallets **38** and that an elevating mechanism **60** occupies a space generally equal to that of one of the pallets. In other words, a top plan view of the track arrangement would show a generally circular track divided into twelve portions or stations, eleven of which contain a pallet **38** with a mold **40** thereon, and an empty station occupied generally by the elevating mechanism **60**.

The elevating mechanism **60** includes a frame **62** having downwardly extending side members **64** and **66** secured at their upper ends to a hanger portion **68** pivotally received within a yoke **70**. Cross members such as **72** may be provided between side members **64** and **66** to increase rigidity. The yoke **70** is secured to one end of a rod **74** the other end of which is connected to a pressure responsive piston contained within cylinder assembly **76** which is rigidly mounted in the cover **14** in sealing engagement therewith. The entire frame **62** may be provided with suitable guide surfaces cooper-

ating with a vertically extending guide member **78**.

Referring to FIGURE 3, it can be seen that the sides **64** and **66** are preferably provided with inwardly directed slots **80** and **82**, which approximate the opening provided by guide members or rails **32** and **34**, adapted to slideably receive the inner and outer edges **84** and **86** of the base pallet **38**.

When the frame **62** is raised to its uppermost position, the slots **80** and **82** are brought into alignment with guide rails **32** and **34** so as to permit a mold **40** and pallet **38** to be moved from rails **32** and **34** into slots **80** and **82**, and after pouring to be repositioned from the slots back on the guide rails.

Each mold **40** is positioned atop its pallet **38** in a manner allowing its filling tube **88** to project downwardly through an opening **90** formed in the pallet. Oppositely disposed clamping brackets **92**, secured to the pallet as by screws **94**, may be provided in order to secure the mold to the pallet.

Although the invention is adapted to the use of a conventional mold in the practice thereof, we prefer to use a mold, such as **40**, which constitutes an invention in itself. The mold **40**, as illustrated, includes a casting cavity having two general portions **96** and **98**. Portion **96** defines a generally elongated cylindrical cavity while portion **98** defines a cylindrical cavity of relatively shorter length and greater diameter.

The wall structure of the mold assembly is preferably formed of a gas permeable ceramic or refactory material and having an external coat **100** such as of glazing which is impermeable. The downwardly depending filling tube **88** is preferably constructed of like material. Conduit **102** of tube **88** contains a construction **104** the purpose of which will be subsequently described.

An additional chamber **106** is formed at the uppermost end of mold **40** by providing a transversely extending wall **108**. The wall **108** is also formed of a gas permeable refractory, but without an impermeable coating.

The arrangement as illustrated in FIGURE 1 also comprises means for intermittently evacuating and pressurizing the chamber **16** of the outer container **12**. In the preferred embodiment of FIGURE 1, a source **110** of inert gas, such as argon, is pneumatically connected as by a conduit **111** to a receiving tank **112** which, in turn, is connected by parallel conduits **114** and **116** to the chamber **16** of the outer container **12**. Valve assemblies **118** and **120** serially connected in conduits **114** and **116**, respectively, are provided for at times terminating communication therethrough. Additionally, the conduit **116** has connected therein a suitable pneumatic pump assembly **122**, of well known kind. A conduit **123**, containing a valve assembly **125** therein, communicates between the chamber **16** and a suitable vacuum pump **127**.

Preferably, the arrangement of FIGURE 1 is also provided with a pressure control apparatus **124** of well known kind, such as disclosed generally by FIGURES 1, 1–A, 2, 2–A, and 2–B of U.S. Patent 2,125,081 issued July 26, 1938, to C. B. Moore. The pressure control apparatus is of the type wherein the desired pneumatic pressure within a controlled chamber, such as **16**, is set or called for by means of an externally mounted normally manually operated selector gear schematically indicated at **126**.

In adapting the control apparatus **124** to the present invention, a conduit **128**, which is equivalent to conduit *b'* of said Patent No. 2,125,081, communicates between the presusre control apparatus **124** and the chamber **16** in order to feed back a signal to the control **124** indicative of the existing pressure within chamber **16**. A control valve **130**, serially connected in conduit **114** and the equivalent of valve, A, of said Patent No. 2,125,081, is

made operative by means of conduit **132** which communicates between the valve **130** and the control **124**.

The pressure control apparatus **124** is preferably further modified by providing an electric motor **134** and suitable gear train **136** to drive and rotate the selector gear **126**, in accordance with the disclosure of U.S. Patent 2,990,592, issued July 4, 1961, to H. H. Hursen. By providing a suitable motor arrangement such as disclosed in said Patent No. 2,990,592, the operation of the control apparatus **124** can be changed from that of only maintaining a particular pressure to one which causes a controlled and uniformly increasing pressure within the chamber **16**. This is achieved, of course, by causing the selector gear **126** to continually rotate in the pressure-increasing direction at a speed dependent on motor **134**. The motor arrangement, per se, forms no part of this invention.

Operation of first embodiment

Without regard to the various controls and control systems disclosed, the overall operation of the invention is as follows:

With the cover **14** open, the induction furnace or ladle **18** is placed in the chamber **16** and charged with the metal to be melted and subsequently cast. Eleven molds **40** and supporting pallets **38** are then properly positioned on guide rails **32** and **34** and the entire cover **14** lowered onto the lower portion **12** in sealing engagement therewith.

After the cover **14** with the molds supported thereby is placed on the tank, the first step is to evacuate the tank of air. This is done by means of the vacuum pump **127**, and while the evacuating step is being performed, the induction coil of the ladle is turned on and the metal melted. After the metal is melted and it is desired to pour, the valve **125** is closed. Thereafter, the table **58** is rotated to bring a first mold **40** into position over the ladle, and then the frame **62** with the pallet and mold thereon, in the position shown in FIGURE 1, is lowered until the pouring tube **88** of that mold is injected into the induction furnace or ladle to a position near the bottom. In the lowering and raising movements of the pallet **38** by the frame **62**, the arm **42** is merely drawn out of the corresponding slot **44** and moved again thereinto to be carried around by the table **58**.

The next step is to introduce the inert gas, argon, into the tank which is done, in the present instance, under the control of the pressure control apparatus **124**. It is so introduced under increasing pressure, and acting on the metal in the ladle it forces it up into the mold. Although the mold was "evacuated" with the evacuation of the tank, there is nevertheless a certain small quantity of air or gas in the mold. As the metal flows up into the mold it forces the air up ahead of it through the gas-permeable transverse wall **138** into the reservoir **106**. The wall **108** will not pass the molten metal therethrough, acting as a stop thereto, and defining the upper limit of the casting cavity. This arrangement avoids trapping of any small quantity of air or gas in the main cavity in which the metal to be cast is introduced, and thus eliminates irregular surfaces or holes in the casting such as would result from trapped gas.

After the filling step is completed, the introduction of argon may be stopped and the mold held at its lowered position until the metal therein begins to solidify, and after sufficient solidification, the mold is raised, and the constriction **104** serves to prevent outflow of metal relative to a uniform passage, for any given degree of solidification of the metal. The gas pressure in the tank working through the pouring tube **88** also assists in retaining the metal in the mold, in view of the relatively rare condition of the gas in the reservoir **106**.

The mold is withdrawn by raising the frame **62** up to its original height and thereafter the motor **58** is again operated to rotate the table **58** to bring the next pallet

38 and the mold thereon into position over the ladle, this action moving the first pallet and mold out of the frame and back into the quick members 32 and 34. After the first mold has been withdrawn from the ladle and before the succeeding mold is lowered into the ladle, the tank is evacuated by means of the compressor 122 which withdraws the argon and forces it into the receiving tank 112. This evacuation of the tank results in the evacuation of the next mold, as well as all the other empty molds. After the tank is thus evacuated to the desired degree, the second mold is lowered into filling position, and the series of steps referred to above are repeated, it being understood that the vacuum pump 127 is utilized only to initially withdraw the air from the tank and that all successive evacuations of the argon gas are accomplished by means of the compressor 122.

The foregoing steps in the actual filling operation may be done manually or automatically, as will be understood. For example, the vacuum pump 127 may be operated under manual control until the air pressure in the tank reaches the desired low point, which may be indicated by a suitable pressure indicator, and the operator then closes the valve 125. Thereafter, he may manually control the valves 120, 130 and 118, while manually controlling the operation of the compressor 122. However, the invention adapts itself to either manual or automatic control, the latter arrangement including the desired control elements for accomplishing the intended purpose; for example, the pressure control apparatus 124 may be automatically controlled to produce the optimum rate of filling the tank with gas pressure, so as to fill the mold with molten metal at the desired rate. Other controls may be incorporated in an automatic arrangement so that the sequential steps are controlled by the movements of the various pieces of the apparatus, such as the movement of the frame 62, rotation of the table 58, the gas pressure in the tank reaching a certain maximum point and a certain minimum point, etc. The exact components or elements making up such automatic control do not enter into the invention as such.

Second embodiment

Attention is now directed to FIGURES 4 and 5 showing apparatus made according to a second embodiment of the invention. The apparatus indicated in its entirety at 140 includes a lower tank 142 defining a ladle chamber 144, and made of separable parts for inserting a ladle thereinto and removing it therefrom, and an upper housing 146 defining a mold chamber 148. This apparatus includes various conduits and valves for connection with controls of FIGURE 1 for controlling the atmosphere in the chambers. These conduits and valves will be referred to individually hereinbelow.

The lower tank 142 includes an inlet conduit 150 having a valve 152 therein, for introduction of an inert gas such as argon into the tank for pressurizing the latter. It also includes an outlet conduit 154 having a valve 156 therein and communicating with a terminal conduit 158 adapted for connection with a vacuum pump. The upper housing 146 includes a conduit 160 having a valve 162 therein, and also connecting with the terminal conduit 158. The upper housing 146 includes an additional outlet conduit 164 having a valve 166 therein which is not connected with any of the other conduits, and independent of the lower tank 142 for release of the vacuum in the upper housing, while the upper housing 146 is sealed from the lower tank 142 in a manner described below.

Mounted in the lower tank 142 is an induction furnace 168, serving as a ladle, heated as by a coil 170 contained within the wall thereof. The induction furnace or ladle may have a pouring lip 172, if desired. The ladle is supported in a cradle 174 which is movable vertically under the control of a plurality of cylinder-ram devices 176, these cylinder-ram devices being operative for elevating the cradle from a lower position shown in FIGURE 4 to an upper position shown in FIGURE 5, and controlling its descent to the lower position. Another cylinder-ram device 178 is interconnected between the cradle and the ladle, and operative for tilting the ladle to a pouring position shown in dotted lines in FIGURE 4 for pouring through the pouring lip 172 into an ingot mold 180 which may be incorporated in the apparatus. The ladle, in so tilting, may fulcrum on an element 182 of the cradle. Reference will be made again hereinbelow to the ingot mold 180. Sight ports 183 are provided for enabling observation of the ladle and other things in the tank when the latter is closed. The cylinder-ram devices 176 and 178, as well as all other enclosed similar devices, are operable from the exterior.

The upper housing 146 is removably supported on the lower tank 142, and for convenience in removability the conduit 160 is provided with a flexible or releasable segment 184 of known kind, here shown diagrammatically. The joint between the upper housing and lower tank is defined by flanges 186 of suitable size and shape having sealing means 188 therebetween for sealing the housing from the exterior.

The lower tank and upper housing have communication through an opening 190 formed in the upper wall of the tank, and a releasably sealed connection 192 is provided for selectively closing the opening and sealing the housing from the tank. This releasably sealed connection may include a shut-off slide 194 having an aperture 195, operated by a cylinder-ram device 196, the slide in the position shown in FIGURE 4 sealing the tank from the housing and in the position shown in FIGURE 5 permitting communication between those two containers.

The mold to be filled is indicated at 198, and includes a bottom pouring tube 200. The mold is mounted for vertical reciprocation by means of a plurality of cylinder-ram devices 202 which are operative for lowering it to its lower position shown in FIGURE 5, and returning it to its upper position of FIGURE 4. Surrounding the upper end of the pouring tube is a tube holder 201 insertable into the aperture 195 and opening 190 when the mold is in lower position, and thus operable for sealing the upper housing from the lower tank.

A shut-off slide 204 is provided for selectively shutting off the mold from its bottom outlet opening through the pouring tube, and this slide is under the control of another cylinder-ram device 206.

Also contained in the upper housing 146 is a pouring tube preheater 208 of suitable kind, and here designated semi-diagrammatically. This tube preheater includes, for example, a heating element 210 and is mounted for horizontal reciprocation under the control of a pair of cylinder-ram devices 212 which are operative for moving the preheater between its operative position of FIGURE 4 and inoperative position of FIGURE 5. When in its operative position of FIGURE 4, the heating element 210 effectively surrounds the tube sufficiently for preheating it to the desired degree, it being understood, of course, that this is done while the mold is in its upper position and preparatory to pouring. For the pouring operation, the preheater is retracted to its inoperative position of FIGURE 5, enabling the mold to be lowered.

Operation of the second embodiment

The first step in the pouring operation is to charge the ladle 170, and place a mold in the upper housing and then place the upper housing on the lower tank, and this may be done before the tank has been evacuated, that is, it may be still filled with air. Thereafter, and while the shut-off slide 194 is in open position of FIGURE 5, the tank and the housing together are evacuated by means of the vacuum pump operating through the terminal conduit 158, while the valves 156 and 162 are both open, it being understood, of course, that valves 152

and **166** are closed. The coil **170** in the induction furnace or ladle may be energized at the beginning of this evacuating operation and continued until the metal is completely melted, which need not coincide with the completion of the evacuation. When the tank and housing are completely evacuated, the valves **156** and **162** are closed, and for the pouring step the ladle is elevated and the mold is lowered, both to the positions shown in FIGURE 5. When the mold is lowered, the pouring tube holder **201** fits into the aperture **195** of the slide plate **194**, as shown in FIGURE 5, as stated above, and seals the passage **190**, for enabling development of pressure in the lower tank while maintaining vacuum in the upper housing.

The pouring step is then performed, which is done by introducing the inert gas, e.g., argon which is to constitute the controlled atmosphere, through the conduit **150**. The introduction of the inert gas is so continued until the pressure in the tank is sufficient to force the metal in the ladle upwardly through the pouring tube and into the mold. After the mold is filled to the desired degree, the shut-off slide **204** is moved to closed position of FIGURE 4, and the mold elevated.

The next step is to remove the filled mold from the housing, and in order to preserve the inert gas that was introduced into the housing, it is drawn out by the vacuum pump through the terminal conduit **158**, and for this operation the valve **162** is opened, but in order to minimize the operation and not withdraw the inert gas from the tank, which is unnecessary, the valve **156** and the shut-off slide **194** are closed. After the upper housing is thus again evacuated, the valve **162** is closed and the valve **166** is opened to permit air to enter the housing to facilitate removing the housing from the tank, the metal in the mold being at this time frozen and not subject to the reaction of the atmosphere, as is molten metal.

The filled mold is then removed from the upper housing, and another mold placed therein and the housing replaced on the lower tank. The foregoing steps with respect to filling are then repeated.

The induction furnace or ladle **168** may remain in the elevated position of FIGURE 5 throughout the pressure pouring of that heat into a plurality of molds.

The lower tank lends itself to use without the housing, for example, alloy pouring. If a different alloy should be desired, the additions thereof may be placed in the ingot mold **180** and then the molten metal from the ladle poured thereinto.

There are numerous advantages of the invention, such as combining vacuum melting with controlled atmosphere pouring. In the case of the second embodiment, because of the closure slide plate **194**, the metal in the induction furnace or ladle can be respectively melted or heated in a vacuum while the housing **146** is removed from the tank, with an obvious advantage in saving of time.

The upper housing **146** may be utilized for making additions to the molten metal in the ladle under vacuum conditions. The pouring tube preheater **208**, being arranged in the upper housing, enables preheating of the pouring tube, also under vacuum conditions.

While we have shown herein certain preferred forms of the invention, it will be understood that changes may be made within the scope of the appended claims.

We claim:

1. Casting apparatus comprising a sealed tank, a ladle of molten metal in the sealed tank, means for evacuating the tank, means for pressurizing the tank, a housing mounted on the tank, means for selectively establishing communication between an opening in the tank and the interior of the housing and for shutting off that communication, a mold in said housing having a downwardly extending pouring tube, means for reciprocating the mold to pass the pouring tube through the opening between the tank and the housing and into the mold metal in the ladle, and to retract the tube from the opening, means for sealing the tank and the housing when the mold is in such lowered position, and means for maintaining a reduced pressure condition in the housing while an elevated pressure condition is established in the tank whereby such elevated pressure condition effects filling of the mold by the molten metal in the ladle.

2. The casting apparatus set out in claim **1** wherein pouring tube heater means is provided in the housing and movable to an operative position in which it effectively surrounds said pouring tube for heating the latter and is retractable to an inoperative position clear of the movements of the mold.

3. The casting apparatus set out in claim **1** wherein said ladle is of the lip-pouring type, a supplementary mold is in the tank, and means are provided for tilting the ladle for pouring therefrom into the supplementary mold.

4. A method of casting molten metal from a ladle in a gas-tight tank having an opening with a releasably sealed connection to a gas-tight housing containing a reciprocating mold having a depending pouring tube that is extendable through the opening in to the molten metal, said method comprising the steps of: extending the pouring tube through the opening into the molten metal, then developing a pressurized atmosphere in the tank at a pressure value higher than that in the housing for forcing the molten metal through the tube into the mold, then withdrawing the tube from the opening, then sealing the opening by closing the releasably sealed connection, and then removing the mold from the housing.

5. A method of casting molten metal from a ladle in a gas-tight tank having an opening with a releasably sealed connection to a gas-tight housing containing a pouring tube heater and a reciprocating mold having a pouring tube that is movable through the opening into the molten metal, said method comprising the steps of: energizing the heater to heat the tube, then extending the tube through the opening into the molten metal, then developing a pressurized atmosphere in the tank at a pressure value higher than that in the housing for forcing molten metal through the tube into the mold, then removing the tube form the molten metal and the opening, then closing the releasably sealed connection thereby sealing the opening, and then removing the mold from the housing.

6. The method set out in claim **5** wherein the successive steps set out in claim **5** are repeated until the ladle contains an amount of metal that is less than the capacity of a mold, and then pouring the remaining metal from the ladle into a supplementary mold in the tank.

7. A method of casting vacuum degassed molten metal from a container in a gas-tight tank having an opening with a releasably sealed connection to a gas-tight housing, said method comprising the steps of: placing a mold having a depending pouring tube into the housing, then developing a vacuum in the housing, then unsealing the opening between the tank and the housing by opening the releasably sealed connection, then extending the pouring tube through the opening into the molten metal, then developing a pressurized atmosphere in the tank at a pressure value higher than that in the housing for forcing molten metal through the tube into the mold, then removing the tube from the metal and the opening, then closing the opening with the releasably sealed connection, and then removing the mold from the housing.

8. A method of casting comprising the steps of: placing a mold in a gas-tight housing, then attaching the housing to a gas-tight tank having a container of molten metal and an opening, with a releasably sealed connection, that is communicable with the interior of said housing, then developing a vacuum in the housing, then connecting the mold to the molten metal by immersing in said metal a tube attached to the mold and extending through the opening, then increasing the gas pressure in the tank by

the addition of an inert gas to a pressure value above that in the housing to force molten metal through the tube into the mold, then terminating the flow of molten metal to the mold, then removing said tube from the molten metal and the opening, then sealing the opening by closing the releasably sealed connection, then removing the housing from the gas-tight tank, and then removing the mold from the housing.

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