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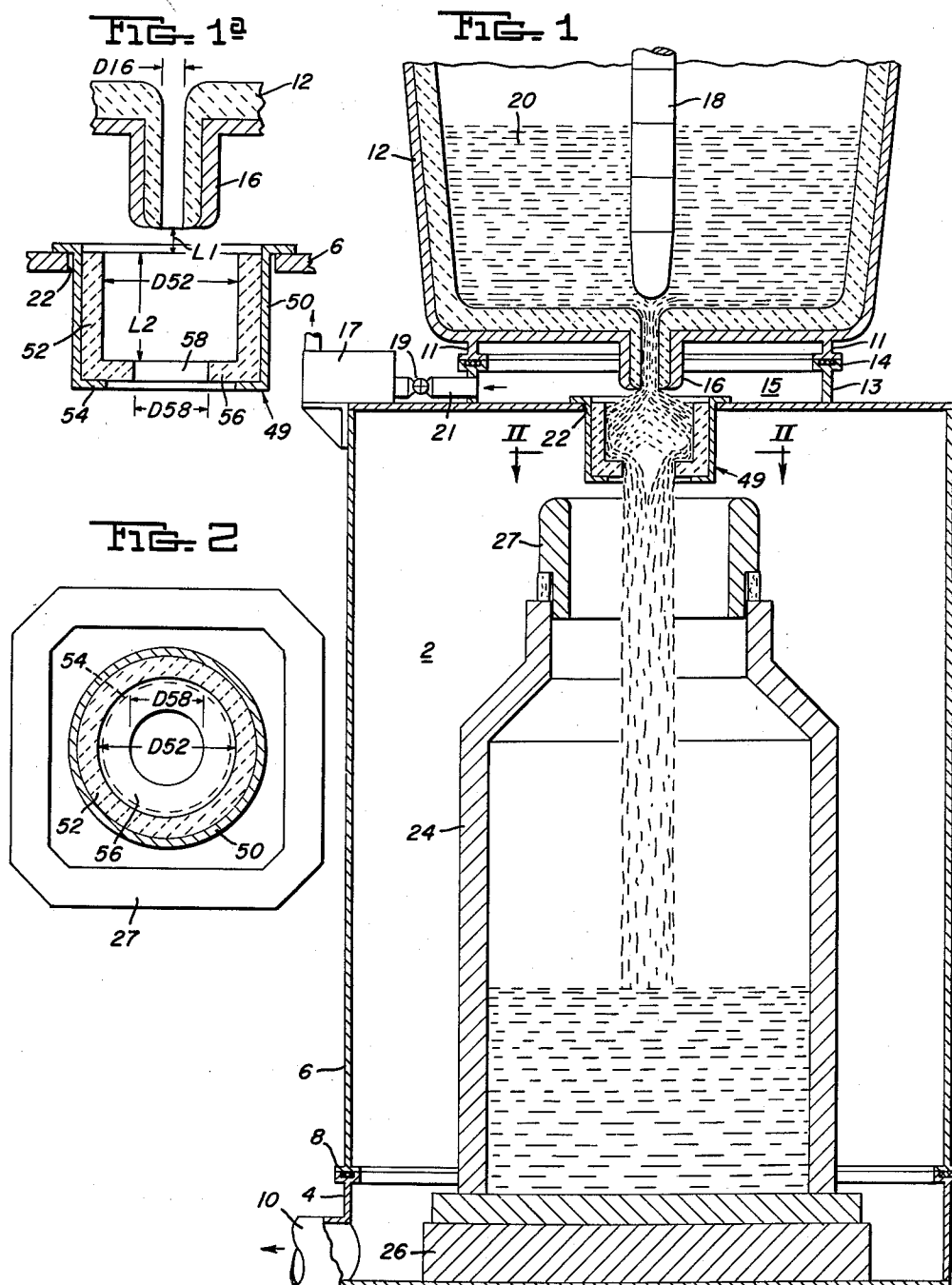
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METHOD AND APPARATUS FOR VACUUM CASTING

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3 Sheets-Sheet 1



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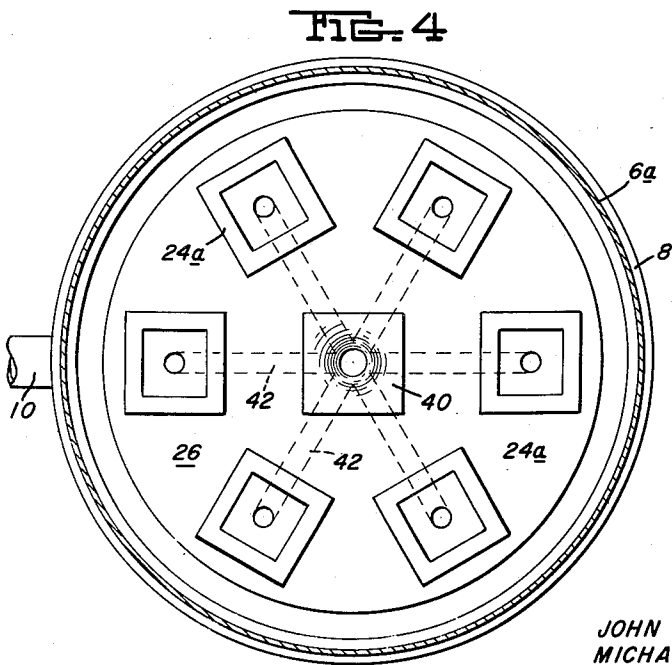
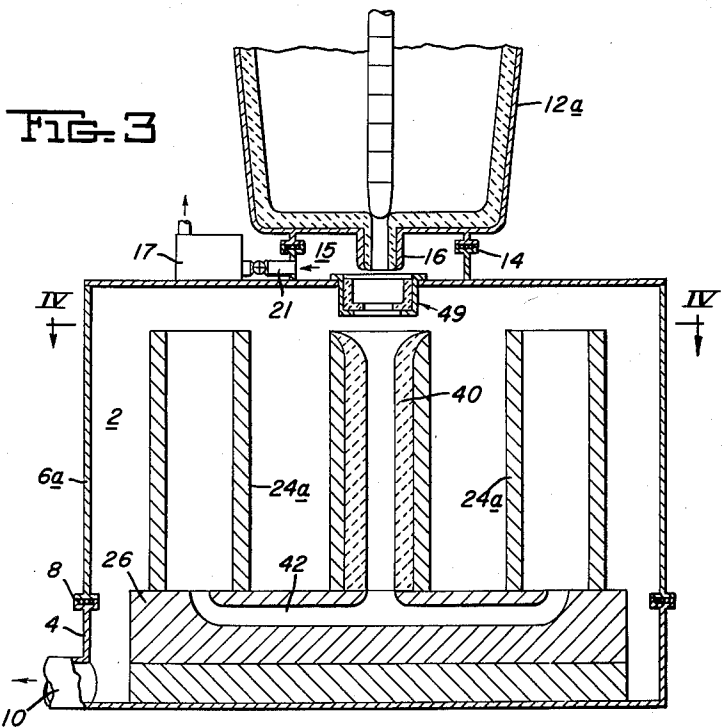
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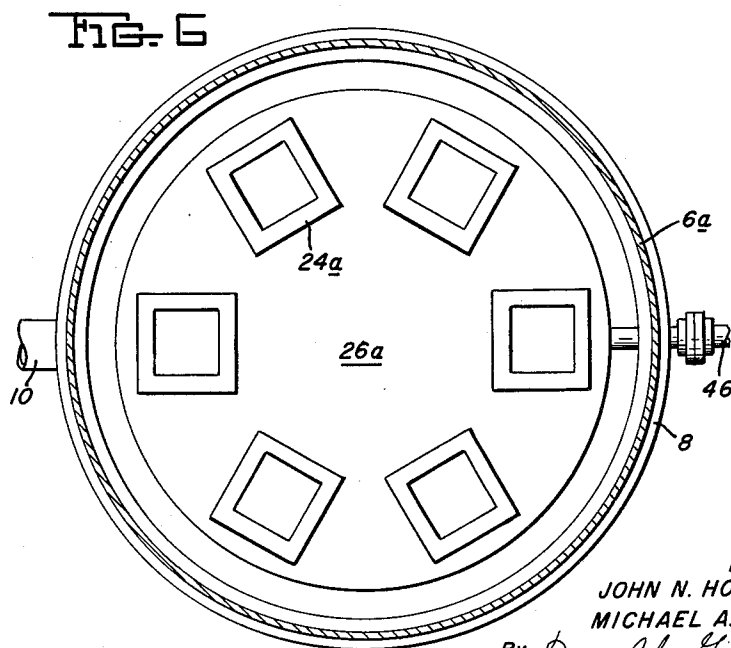
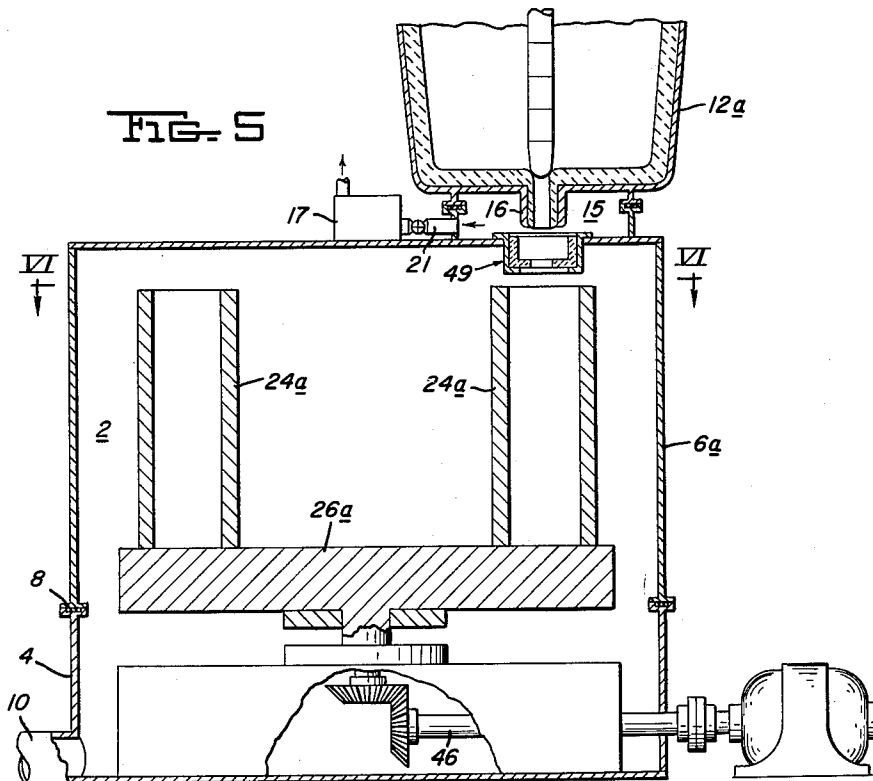
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METHOD AND APPARATUS FOR VACUUM CASTING

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This invention relates to vacuum casting of metals and more particularly to an improved method and apparatus for vacuum casting of ferrous metals.

The deleterious effects of a few parts per million of hydrogen picked up during the refining of a heat of steel are widely recognized and it has been proposed to lower the hydrogen content of steels, particularly those for large forgings and similar applications, by teeming the metal into ingots in an evacuated chamber. For many applications a hydrogen content of less than 1.5 p.p.m. is desired, and we have found that to achieve such low concentration within the limited times of teeming which must be observed, a pressure less than about 1 mm. of mercury and preferably less than about 0.5 mm. must be maintained in the casting chamber. In pouring steel into an atmosphere of such low pressure, the stream of metal leaving the pouring nozzle is immediately and violently broken up into a conically shaped spray having an apex angle of about 130°. As a result, not only does an appreciable portion of the metal fall outside the mold but a considerable portion washes over the surface of the hot top or impinges upon the inner walls of the mold. The portion of spray washing the hot top detaches particles of refractory which contaminate the ingot, while those droplets impinging upon the mold walls result in an ingot having a spongy or scabby surface requiring expensive surface conditioning and other undesirable characteristics.

It is accordingly an object of this invention to overcome the foregoing deficiencies and difficulties in vacuum casting of steel ingots and provide a method and apparatus for achieving good surface on ingots cast in highly evacuated chambers.

We have found that the ideal teeming stream from a surface quality standpoint is one similar to that obtaining when casting in air. While such stream is achieved at chamber pressures of about 20 mm., appreciable reduction in hydrogen content does not occur above about 8 mm. pressure at which pressure only about 20 percent of the hydrogen is removed. Decreasing chamber pressures below 8 mm. increases the amount of hydrogen removed but spraying becomes increasingly violent, becoming intolerable at a pressure of about 2 mm. Since even at 2 mm. pressures the hydrogen content is not reduced below about 2 p.p.m., it is evident that application of the vacuum degassing principle in steel making has been seriously limited.

Moreover, even in those instances where a moderate reduction in hydrogen might be considered an improvement, present vacuum casting practices do not produce a completely satisfactory ingot surface. This, we have found, is attributable to the fact that a considerable portion of the total degasification accomplished at pressures where spraying is not a problem occurs in the mold itself and is accompanied by a boiling at the surface of the metal in the mold. The splashing attending the boiling action produces a scabby ingot surface and makes filling the mold to the necessary level in the hot top a costly and time consuming operation.

Accordingly, further objects will be apparent from the following specification when read in conjunction with the attached drawings, wherein:

FIGURE 1 is a vertical sectional view of the apparatus of our invention;

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FIGURE 1a is an enlarged detail;

FIGURE 2 is an enlarged horizontal section on line II—II of FIGURE 1;

FIGURE 3 is a vertical sectional view of apparatus for bottom-casting a plurality of small ingots;

FIGURE 4 is a view taken on the line IV—IV of FIGURE 3;

FIGURE 5 is a vertical sectional view of apparatus for top-pouring a plurality of small ingots; and

FIGURE 6 is a view taken on the line VI—VI of FIGURE 5.

Referring more particularly to the drawings, the numeral 2 designates a vacuum casting chamber enclosed by a base portion 4 and a removable cover portion 6 having a suitable seal 8 therebetween. An exhaust duct 10 connects the chamber 2 through the base 4 to suitable exhaust pumps, not shown. For the purpose of the present invention, the latter must be capable of maintaining the chamber 2 at a pressure below 1 mm. of mercury while teeming metal of an anticipated maximum hydrogen content into the apparatus at a desired maximum rate. The base 4 and cover 6 are formed of sheet steel or other metal of sufficient strength to withstand external atmospheric pressure when the inner pressure is as low as 0.1 mm. and to support the weight of a pouring or basket ladle 12 and the molten metal 20 contained therein. Ladle 12 is provided with a downwardly extending, flanged ring portion 11 attached to the bottom thereof in a gas-tight manner and resting upon a similar flanged ring 13 similarly attached to the top of cover 6 to extend upwardly therefrom. A suitable sealing element 14, e.g., a compressible O ring is provided between the flanges of rings 11 and 13 to effect a gas-tight seal. The bottom of the ladle together with rings 11 and 13 and the top of the cover define a sub-chamber 15 which opens into chamber 2 through a hole 22 in the top of cover 6. Chamber 15 is connected to an auxiliary vacuum pump 17 through a control valve 19 in pipe 21 attached to ring 13. The pump 17 must be of sufficient capacity to maintain sub-chamber 15 at a pressure no greater than 2.5 mm. of mercury during the teeming operation. The ladle has a conventional refractory lined nozzle 16 of diameter D-16 disposed in the midportion of its bottom over hole 22. The nozzle is adapted to be closed by a stopper rod 18 which is raised and lowered by a conventional lever arrangement (not shown), whereby molten metal 20 can be teemed through sub-chamber 15 into a suitable mold 24 disposed on a support member or base 26 in chamber 2 and below the hole 22. Numeral 27 identifies a conventional hot top carried by the mold.

As shown in the modifications of FIGURES 3 through 6, our invention contemplates the casting of a plurality of smaller ingots 24a within an enlarged chamber or tank 6a. FIGURES 3 and 4 show our invention as adapted to bottom pouring the ingots through a central sprue 40 connected to the bottom of the molds by individual runners 42. In this modification, the nozzle 16, opening 22 and sprue 40 are disposed centrally of the chamber.

In the modification of FIGURES 5 and 6, the base 26a is rotatably mounted and is adapted to be rotated by a motor through suitable shafting and gearing 46. In this modification, the basket 12a is eccentrically mounted on the cover 6a.

Common to the various modifications shown, a collar assembly indicated in general by 49 is supported in the opening 22 by the cover 6 and is comprised of a shell 50 and a removable liner 52 which may be metal or refractory. The shell 50 has an inwardly projecting flange 54 to support the insert 52. The insert likewise has an inwardly projecting flange 56 which provides an opening 58 of a diameter D-58 which is substantially smaller than the diameter D-52 of the main body portion of the insert.

In developing the method of our invention we have found teeming can be conducted at any conventional rate, i.e., the new conditions of pressure which must be practiced to achieve our results impose no additional limitation as respects teeming rate. Accordingly, since it is desirable to complete teeming in as short a time as possible, the diameter D-16 of our pouring basket nozzle will be selected to provide a desired maximum rate of flow which will vary with the size of ingot to be cast in the known manner. Thus, in the case of a 200 ton ingot, a nozzle diameter of 2 to 3 inches providing teeming rates of 10 to 20 tons per minute may be used; while for smaller ingots, nozzles down to a minimum of about 1 inch may be provided. Selection of teeming rate is largely a matter of providing a rate of rise of metal in the mold commensurate with the mold size so that filling of the mold to the desired level may be conveniently controlled.

The present invention contemplates treating steel containing as much as 9 p.p.m. of hydrogen and reducing the concentration of this element to less than 1.5 p.p.m. As previously mentioned, this result requires the teeming to be conducted at a pressure of less than 1 mm. of mercury, at which pressure an intolerable spraying of the metal stream is occasioned by the gas evolution. Collar assembly 49, when properly proportioned and positioned with respect to the bottom of nozzle 16, serves to confine this spray; while properly proportioning the internal diameter D-58 of the flange 56 of insert 52 to the nozzle diameter D-16 reforms the collected spray into a substantially solid stream. In the latter respect, D-58 should be no more than about 5 times nor no less than about 2 times diameter D-16. Larger openings will not sufficiently re-form the stream and while some benefit accrues from merely directing the spray into a falling column of discrete particles, complete elimination of ingot surface defects is not accomplished thereby. A diameter D-58 less than 2 times D-16 may not pass metal rapidly enough to prevent the collar 52 from filling and overflowing into the sub-chamber 15.

Other dimensions of the collar assembly and its location with respect to the ladle nozzle and the top of the mold hot top are also of significant importance. Obviously it must be disposed to catch all of the spraying stream, however, it must not surround the nozzle so as to prevent or impede movement of the released gases into sub-chamber 15. Accordingly, the distance L-1 from the top of the insert to the bottom of nozzle 16 must be no less than 1 inch and the internal diameter D-52 of the insert must be at least 4.7 times L-1 and preferably 4.7 times L-1 plus D-16. The distance L-1 may be increased providing the minimum ratio of D-52 to L-1 is maintained; in fact, it is preferable to use a distance L-1 of about 3 inches, in which case D-52 is a minimum of about 14 inches and preferably should be 14 inches plus the diameter of the ladle nozzle. The dimension D-52 applies to the top of the insert; that is, the insert need not be a uniform diameter throughout its length L-2 but can be, if desired, provided with sides sloping to the internal diameter D-58 of its flange. In fact, the insert rapidly assumes this shape as the result of metal skull formation during the early stages of the teeming when the insert is cold. The length L-2 of the insert must be at least equal to its largest internal diameter in order to accomplish collection of the spray into the desired stream. L-2 may be greater if desired so long as the collar assembly terminates sufficiently above the hot top so that the stream and metal level in the mold can be observed during the teeming.

In addition to the foregoing limitations, to produce ingots containing less than 1.5 p.p.m. of H_2 and still achieve optimum surface quality requires the metal to be degasified substantially to the desired end point in sub-chamber 15. If this is not accomplished a second spraying of the metal occurs below the collar assembly in chamber 2. Although the mass of the hydrogen evolved in sub-chamber 15 is small, its volume at the pressures required for

its release is enormous. For example, at a chamber pressure of 1 mm. Hg. and a teeming rate of 10 tons per minute, each p.p.m. of H_2 released from the steel occupies a volume of 2730 c.f.; thus, 20,475 c.f.m. of H_2 are released in reducing the H_2 content to 1.5 p.p.m. from a steel containing 9 p.p.m. in the ladle. Further, the volume of evolved gas is actually somewhat greater than this since some O_2 (as CO) and N_2 are also released; while amounts of the latter vary considerably from steel to steel, they can increase the total gas evolution under the above conditions to as much as 60,000 c.f.m., which volume will be further increased by any in-leakage of air. Unless this gas is removed as it is evolved, the pressure in sub-chamber 15 builds up, reducing the amount of gas released therein. Some increase in pressure in the immediate vicinity of the gas evolution of course cannot be avoided; however, we have found that if the pressure in sub-chamber 15 is prevented from rising above 2.5 mm. Hg, the metal leaving collar 52 will contain no more than about 2.5 p.p.m. of hydrogen and an additional 1 to 1.5 p.p.m. of this element will be released from the stream as it enters chamber 2 without disruptive spraying of the stream. A portion of the gas released from the stream in chamber 15 will pass through the opening 58 in insert 52. However, since the size of opening 58 must be limited to effect the desired stream formation, the amount of freed gas leaving through this opening is limited and a major portion of the gas must be removed by some additional means. Auxiliary pump 17 is provided for this purpose; however, if desired line 21 could be connected directly to exhaust line 10 or as an alternative or supplement to the pump 17, additional openings between the sub-chamber 15 and chamber 2 can be made in cover 6. If this latter provision is made, the main pumps serve to remove gas evolving in the sub-chamber 15 through chamber 2 without the gases passing through opening 58. To be effective, such additional openings must have considerable cross sectional area, for example, at a teeming rate of 8 ton per minute of steel containing 9 p.p.m. H_2 , they must be at least 80 to 100 sq. inches in area.

As indicated by the foregoing discussion, the method of the present invention comprises introducing a stream of molten steel contaminated with hydrogen into a first chamber maintained at a pressure below 2.5 mm. of mercury wherein the stream is explosively dispersed into a spray and its hydrogen content reduced to less than about 2.5 p.p.m., collecting and re-forming the substantially degasified spray into a substantially solid stream, introducing the re-formed stream into a second chamber maintained at a pressure of less than about 1 mm. of mercury wherein the hydrogen content of the stream is reduced to less than 1.5 p.p.m. without disruption of the stream and then collecting the stream in a suitable shaped mold maintained in the second chamber. In practice, we prefer to maintain the second chamber at a pressure of about 0.5 mm. Hg. At this pressure the method will consistently produce clean ingots free of surface defects and containing less than 1.0 p.p.m. of H_2 . The method is adapted to production of ingots of any desired size by either bottom or top pouring practices.

The pouring of a 200 ton ingot in the apparatus of FIGURE 1 will serve to illustrate preferred practices of our invention. After the mold and hot top are positioned on base 26 and cover 6 and basket ladle 12 positioned on their respective seats, the apparatus is evacuated to a vacuum of at least 0.5 mm. Hg. Basket ladle 12 is then charged with molten steel 20 from a suitable transfer ladle. With all pumps in operation, metal from ladle 12 is introduced into sub-chamber 15 through nozzle 16 having a diameter of $2\frac{1}{4}$ inches to provide a teeming rate of about 10 tons per minute. To assure this rate during the course of the cast, the level of metal in basket 12 will be maintained reasonably constant by additions thereto from the supply in transfer ladle. Pump 17 is regulated by control valve 19 to remove a major portion

of gas evolving from the entering stream; the balance of released gas leaving the sub-chamber 15 with the stream through opening 58 in collar insert 52. We prefer to maintain the pressure in sub-chamber 15 as nearly equal to that in chamber 2 as possible; however, some rise in pressure will occur during the course of teeming but this will not be detrimental so long as the pressure is maintained below 2.5 mm. Hg. The spraying stream is collected by the collar assembly 49 and passes into chamber 2 through opening 58 as a substantially solid or continuous stream to fall as such into mold 24. Pressure in chamber 2 is preferably maintained at about 0.5 mm. Hg. However, release of additional gas from the metal in this chamber together with released gas entering from sub-chamber 15 with the metal stream, tends to cause a pressure rise; the latter is not detrimental so long as the pressure is maintained below 1 mm. Hg by suitable regulation of the main pumping system. Upon completion of pouring, the apparatus is returned to atmospheric pressure and the cover removed.

This application is a continuation-in-part of our co-pending application Serial No. 652,038, filed April 10, 1957, now abandoned.

While we have shown and described several embodiments of our invention, it will be understood that these embodiments are merely for the purpose of illustration and description and that various other forms may be devised within the scope of our invention, as defined in the appended claims.

We claim:

1. Apparatus for simultaneously degassing and casting metal including a vacuum chamber having an opening in the top thereof, a mold having a molten metal receiving opening disposed therein, means mounting a ladle above said chamber closing the opening in said vacuum chamber, said ladle having a nozzle in the bottom thereof to deliver a stream of molten metal from said ladle into said chamber through said chamber opening, means at the top of said chamber supporting a collar below said nozzle, said collar being spaced from said nozzle a sufficient distance from the nozzle to permit free movement of the hydrogen released from the stream to thereby permit said stream to be continuously exposed to reduced pressure at said nozzle opening whereby the stream is violently broken up into a spray and substantially degasified as it leaves the nozzle, said collar having an inside diameter at least 4.7 times the distance between said collar and said nozzle plus the diameter of said nozzle, the length of said collar being at least equal to the largest inside diameter of the collar to confine all of said spray and reform said stream, an inwardly extending flange in the bottom of said collar to shape the stream leaving the collar and direct it into the opening in said mold, said inwardly extending flange having an internal diameter at least twice but no more than five times that of said ladle nozzle, and means to maintain a pressure less than 2.5 mm. of mercury at said nozzle opening above said collar and a pressure less than 1.0 mm. of mercury below said collar and around said mold.

2. Apparatus for simultaneously degassing and casting metal including a vacuum chamber having an opening in the top thereof, a mold having a molten metal receiving opening disposed therein, means supporting a ladle above said chamber sealing the opening in said vacuum chamber, said ladle having a nozzle in the bottom thereof to deliver a stream of molten metal from said ladle into said chamber through said chamber opening, means on the top of said chamber supporting a collar in said opening beneath said nozzle, said ladle supporting means and said collar supporting means forming a sub-chamber below said nozzle, said collar being spaced at least 1" from said nozzle to permit said stream to be continuously exposed to reduced pressure at said nozzle opening whereby the stream is violently broken up into a spray and substantially degasified as it leaves the nozzle, said collar having an inside diameter at least 4.7 times the

distance between said collar and said nozzle plus the diameter of said nozzle, the length of said collar being at least equal to the largest inside diameter of the collar to confine all of said spray and reform said stream, an inwardly extending flange in the bottom of said collar to shape the stream leaving the collar and direct it into the opening in said mold, said inwardly extending flange having an internal diameter at least twice but no more than five times that of said ladle nozzle, and means to maintain a pressure less than 2.5 mm. of mercury at said nozzle opening in said sub-chamber and a pressure less than 1.0 mm. of mercury below said collar and around said mold in said chamber.

3. In the method of simultaneously degassing and casting molten steel containing dissolved hydrogen therein to produce forging ingots characterized by teeming the molten steel into a mold disposed in a vacuum chamber to reduce the hydrogen content thereof to less than 1.5 p.p.m., the improvement comprising introducing a stream of said steel through a nozzle having a diameter affording a desired teeming rate into a sub-chamber area within said chamber, continuously maintaining a pressure less than 2.5 mm. of mercury around the stream as it enters the sub-chamber area to explosively disperse said stream into a spray and substantially reduce its hydrogen content to less than about 2.5 p.p.m., collecting and reforming said substantially degasified spray of metal into a substantially solid, unconfined, free-falling stream by passing said spray into a collar disposed below and at least 1" from said nozzle to permit free movement of the hydrogen released from the sprayed stream into the sub-chamber area and thereby maintain the pressure around the entering stream below 2.5 mm. of mercury, said collar having an inside diameter at least 4.7 times the distance between the nozzle and the collar plus the diameter of the nozzle, a length equal to at least said inside diameter whereby the collar will confine all of said spray and an opening in the bottom thereof of a diameter not less than two times nor more than five times the diameter of said nozzle, passing said reformed stream from the collar into the main chamber having the mold disposed therein, maintaining a pressure around said reformed, solid stream and mold of less than 1.0 mm. of mercury to reduce the hydrogen content of the cast steel to less than 1.5 p.p.m., said reformed stream remaining substantially solid during said final reduction in hydrogen content by reason of the initial reduction of hydrogen to less than 2.5 p.p.m. before reforming it whereby a casting substantially free of both surface and internal defects is obtained.

4. A method for simultaneously degassing and casting molten steel to produce ingots characterized by internal soundness and freedom from surface defects comprising introducing a stream of molten steel containing hydrogen dissolved therein into a sealed chamber, continuously maintaining a pressure of not more than 2.5 mm. of mercury around said entering stream to explosively disperse the stream into a spray releasing a predominate portion of the dissolved hydrogen and reducing the hydrogen content of the metal to at least 2.5 p.p.m., continuously collecting and reforming said spray into a substantially solid, unconfined, free-falling stream of molten steel while within said chamber, introducing said solid, unconfined, free-falling stream containing not more than 2.5 p.p.m. of hydrogen into a mold in said chamber in maintaining a pressure of not more than about 1.0 mm. of mercury around said solid, unconfined, free-falling stream and mold to further reduce the hydrogen content of the cast steel to less than 1.5 p.p.m., said initially reduced hydrogen content of not more than 2.5 p.p.m. being insufficient to cause spraying of said reformed stream during said final hydrogen reduction whereby an ingot substantially free of both surface and internal defects is produced.

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