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METHOD AND APPARATUS FOR DEGASSING AND CASTING METALS IN A VACUUM

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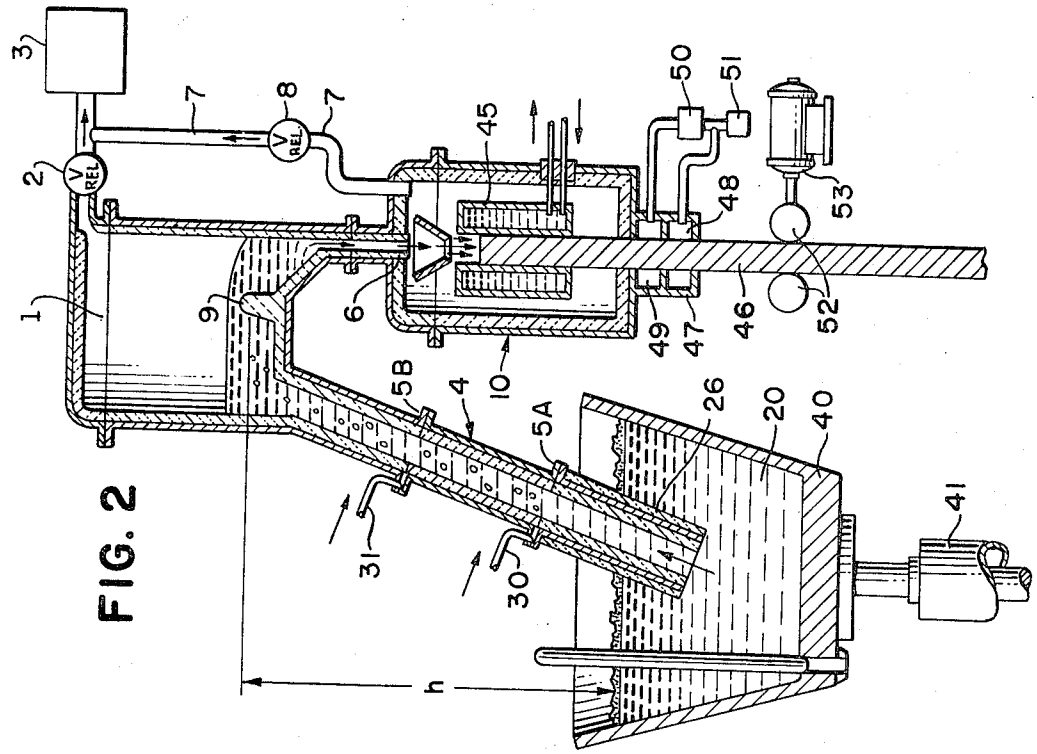

FIG. 2

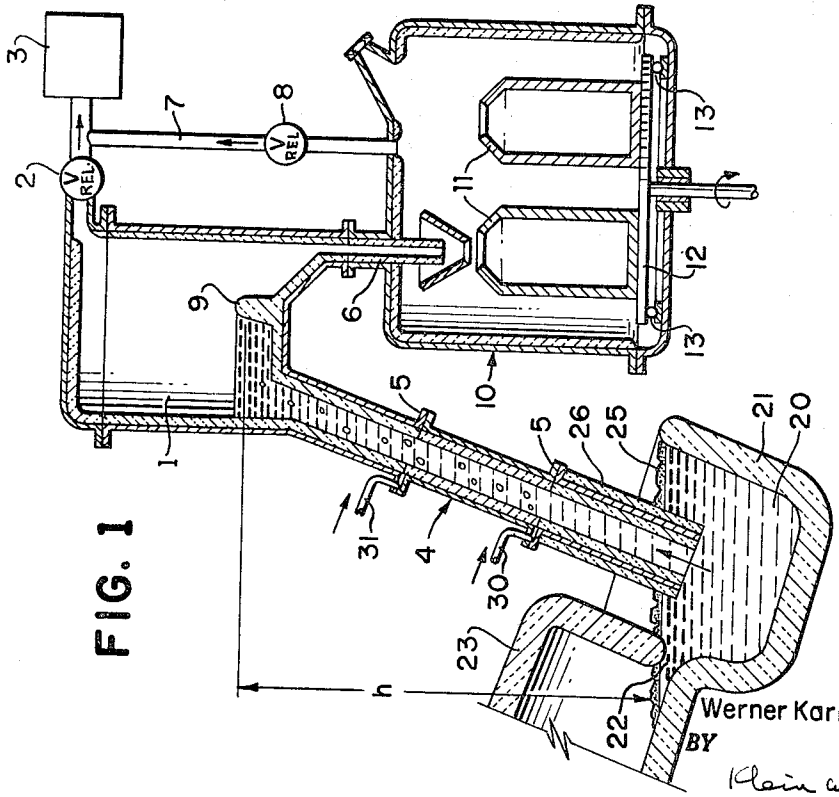

FIG. 1

INVENTOR:
Werner Karl ARMBRUSTER
BY
Klein and Padlon
ATTORNEYS

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METHOD AND APPARATUS FOR DEGASSING AND CASTING METALS IN A VACUUM

Werner Karl Armbruster, Hanau am Main, Germany, assignor, by mesne assignments, to Rheinstahl Huttenwerke Aktiengesellschaft, Essen, Germany

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The present invention relates to a method and an apparatus for degassing and casting molten metals, especially steel, in a vacuum, and more particularly for removing the molten metal directly from the melting furnace, degassing it, and casting the degassed metal without coming in contact with air.

There are various methods known for degassing molten metals and especially steel in a vacuum. All of these methods have, however, certain disadvantages. Thus, for example, the vacuum casting method generally requires the metal to be poured twice in the air, that is, when tapping it from the furnace and when pouring it into an auxiliary ladle which is located above the intake opening of the vacuum vessel. This double repouring of the metal is very detrimental to the refined material.

In a number of other known methods a casting ladle is employed to serve as a container of the molten metal during the degassing operation. These methods, the circulation and siphon methods and also the "ladle degassing" method, normally require the treated metal to be cast with the access of air. Even though this may also be done in a protective gas atmosphere, the use of such a gas no longer permits these methods to be carried out in the normal manner, and despite the consumption of large amounts of gas it is usually not possible to prevent an access of air completely so that the effect of the degassing operation is again at least partly lost.

The vacuum induction furnaces as are now frequently used only have a limited capacity and can therefore be used only for small charges. Furthermore, they do not permit the usual slag treatment to be carried out. Although in some cases such furnaces have lately been built for larger charges, they are so expensive as to be economical only when employed for subjecting very expensive metals to such a vacuum treatment.

Although vacuum arc furnaces and electron beam furnaces may now also be built for larger charges, the treatment of the metal in these furnaces is likewise expensive, even though not quite as expensive as that in an induction furnace. Furthermore, especially for melting larger charges they require the metal already to be degassed befor it enters the furnace, namely, in the form of a precast consumable electrode, in order to avoid any interfering gas discharges.

It is an object of the present invention to provide a simple and therefore relatively inexpensive apparatus and a new method for treating and casting molten metals, especially steel, in a vacuum in a manner so as to overcome the above-mentioned disadvantages of the conventional methods. For conveying the metal through the apparatus the new method relies upon the feeding of a gas into the intake pipe of the apparatus in a manner as similarly employed in the above-mentioned circulation method in which the molten metal which is to be degassed is withdrawn from a container by means of a vacuum siphon, passed through the upper evacuated part of the siphon, and then returned to the same container.

The principal features of an apparatus according to the invention for degassing and casting molten metals, especially steel, in a vacuum, which apparatus also employs such a vacuum siphon, are that the outlet pipe of the vacuum siphon terminates into a vacuum chamber, that the intake pipe of this siphon has a length substantially equal to or greater than the height of the metal therein, and that the intake pipe is provided at least at two points at different levels with means for injecting a gas into the molten metal. Another feature of the invention consists in providing several exchangeable ingot molds or a continuous-casting mold in the vacuum chamber and in such a manner that the operation of changing the ingot molds or of continuously withdrawing the cast metal bar from the continuous-casting mold and the vacuum chamber may be carried out without affecting the vacuum in the vacuum chamber.

According to the invention, the operation of this apparatus which is provided with one or more gas inlets into the intake pipe preferably proceeds in such a manner that when a casting operation is to be carried out the amount of gas to be inserted into the intake pipe and the molten metal therein will be sufficient to insure that the molten metal will flow from the upper end of the intake pipe into the outlet pipe, while during intermissions in the casting process, for example, for changing the molds, the rate of feed of the gas will be regulated so as to be so small that no overflow of the metal will occur into the outlet pipe. For exactly regulating the amount of overflow of the molten metal, for example, for carrying out a continuous casting operation, the invention provides for an accurate control of the rate of feed of the gas. If the intake pipe is provided with two gas inlets, these controlled variable amounts of gas are preferably inserted at the higher point in the form of a pure inert gas such as argon, while at the lower point, a reacting gas is inserted which may consist, for example, of an inert gas with a certain component of hydrogen if it is primarily intended for eleminating oxygen, or with a certain component of chlorinating substances if it is primarily intended for eliminating hydrogen.

The lower end of the intake pipe of the vacuum siphon is of course immersed into the molten metal which is to be conveyed, degassed, and cast. This metal may for this purpose be held in any suitable container, for example, a casting ladle or an intermediate ladle. It is, however, especially of advantage to immerse the end of the intake pipe into the furnace itself or into a trough which is provided at the taphole of an arc furnace. The molten metal will then not come at all into contact with air along its entire path from the furnace to the mold and during the entire time from its discharge from the furnace until it is solidified in the mold. In this manner it is possible to utilize the degassing or vacuum treatment for several purposes, namely, for the action of a flush gas and a reaction gas upon the metal, for carrying out the casting operation and for the degassing process in the degassing vessel, during the casting of the metal into the mold, and during its stay in the mold until it solidifies.

The above-mentioned and still further features and advantages of the invention will become more clearly apparent from the following detailed description thereof which is to be read with reference to the accompanying drawings, in which—

FIGURE 1 shows diagrammatically a cross section of an apparatus according to the invention for degassing and casting steel directly from the furnace into individual ingot molds; while

FIGURE 2 shows a similar view of an apparatus for continuous casting.

In the apparatus as illustrated in FIGURE 1, the degassing vessel 1 is evacuated through a valve 2 by a pump unit 3. The degassing vessel is provided with a long intake pipe 4 which consists of several sections which are connected to each other by flanges 5. The outlet pipe 6 of the degassing vessel 1 terminates into a hermetically closed chamber 10 which in this particular embodiment of the invention is evacuated by the same pump unit 3

through a line 7 and a valve 8. Chamber 10 contains several ingot molds 11 on a turntable 12 which may be controlled from the outside to be turned for a predetermined distance on rails, rollers, or the like 13 to remove a filled mold 11 from the place underneath the pouring funnel at the end of the outlet pipe 6 and to replace it by an empty mold 11.

The lower end of the intake pipe 4 is immersed into the molten metal 20 which is to be degassed and cast, and which is then contained in a trough 21 which is connected to a tiltable arc furnace 23 adjacent to its tap-hole 22. The molten metal 20 in the trough 21 is covered by a layer of slag 25 which for the purpose of the method as described herein is preferably specially reinforced. The pipe section 26 of the intake pipe 4 which is to be immersed into the molten metal is preferably made in the conventional manner of three separate layers, namely, an inner and an outer ceramic layer and an intermediate layer of metal, in order to attain a good sealing effect. The other sections of the intake pipe 4 and at least the degassing vessel 1 are also provided with a refractory lining in the manner as indicated in the drawing.

According to the invention, gas is conducted into the intake pipe 4 above the surface of the molten metal in the trough 21. In the particular embodiment as illustrated in FIGURE 1, this is done at two points, namely, through the gas lines 30 and 31 leading to the two sets of adjacent flanges 5 where the surface irregularities of the butt joints between the lining of the adjacent pipe sections leave a sufficient number of pores to permit the gases to penetrate through these pores into the pipe 4 and the molten metal therein, whereas these pores are so small that the metal will not penetrate therethrough to the flanges 5.

The operation of the apparatus according to FIGURE 1 is as follows:

After the steel is produced in the usual manner in the arc furnace 23, the electrodes (not shown) are lifted out of the furnace and the furnace is then tilted to such an angle that the trough 21 is filled with the molten metal 20. For the vacuum treatment, a slag cover 25 is applied upon the molten metal 20.

The apparatus according to the invention including the degassing vessel 1 and the vacuum chamber 10, is then lowered, for example, by a crane on which it is hanging, until the end of the pipe section 26 will be immersed into the molten metal 20 in trough 21. Valves 2 and 8 are then opened and the pump unit 3 is switched on. It reduces the pressure in the chambers 1 and 10 so far that the molten metal will rise in the intake pipe 4 up to a barometric level *h* which corresponds to the difference in pressure between the outer atmosphere and the vacuum in the apparatus. At the same time, a reacting gas is conducted through the line 30 into the metal in the intake pipe 4 in the manner as above described.

The amount of this gas or, if it is mixed with an inert gas, the reacting component of the mixture is determined in accordance with the amount of steel with which it is to be mixed and the desired effect to be attained, for example, to eliminate oxygen from the steel. The amount of gas fed into the molten steel should, however, also be determined in accordance with its elevating effect upon the steel so that the latter will not rise considerably above the level *h*.

This last-mentioned feature which is also indicated in FIGURE 1 is of considerable importance for the proper operation of the apparatus since, at least when no flush gas is added, the molten metal should not run over into the outlet pipe 6 so that the casting operation may be interrupted, for example, in order to permit the molds 11 to be changed. If the intake pipe 4 does not have a sufficient length for this purpose and does not reach the level *h*, a hump forming an overflow stop 9 may be provided on the base of the degassing vessel 1. This overflow stop 9 consists of a refractory material which may also be reinforced.

In the foregoing description of the operation of the apparatus it was assumed that the gas was only fed into the intake pipe 4 through the gas line 30 at the lower flanges 5, but not at the upper flanges. If this gas is reactive, the insertion thereof at such a low point is very advantageous since the gas bubbles can then travel for a long distance in the molten metal before leaving it in the degassing vessel 1 where the gas is then sucked off by the pump unit 3. Of course, it is also possible to feed the gas into the intake line at the upper flanges 5 or at both the upper and lower flanges. Apart from any desired reaction to be attained by this gas, the location of the point or points where the gas is to be fed into the intake pipe 4, as well as the type and amount of this gas depend, however, primarily upon its buoyant effffect upon the molten metal which is produced by the gas bubbles which should not be so strong that it might cause the molten metal to run over into the outlet pipe 6 and thereby start a casting process.

However, when the time comes at which a casting operation is to be carried out, the amount of gas which is fed into the intake pipe is considerably increased. This may be done, for example, by feeding in an inert gas also through the upper gas line 31. The buoyancy of the much greater number of gas bubbles in the molten metal then drives the metal upwardly and causes it to flow over the hump 9 into the outlet pipe 6 so that the casting process is started. The rate at which this process should be carried out may also be regulated by varying the amount of gas which is fed into the intake pipe 4. When the mold 11 directly underneath the outlet pipe 6 is filled, the gas supply is again reduced to the original amount so that the metal will no longer flow over the hump 9 and the casting process will thus be interrupted. The turn-table 12 may then be turned for the required distance to change the filled mold 11 for an empty mold, whereupon the casting process may be repeated in the manner as above described.

FIGURE 2 illustrates the apparatus according to the invention while the casting process is being carried out, that is, while such an amount of gas is being fed into the intake pipe 4 that the molten metal flows over the hump 9 into the outlet pipe 6. This apparatus differs from that as shown in FIGURE 1 by the fact that the molten metal to be degassed is not taken directly from a part of the furnace but from a casting ladle or the like 40 which is placed on a hydraulic lift 41 to permit it to be raised and lowered relative to the intake pipe 4, inasmuch as in this case the main apparatus itself is stationary. This ladle 40 may also be refilled with molten metal during the casting process.

The apparatus according to FIGURE 2 differs further from the apparatus according to FIGURE 1 by the fact that the vacuum chamber 10 contains a water-cooled continuous-casting mold 45. The metal bar 46 which is thus produced passes from chamber 10 to the outside through a vacuum-tight duct 47 which preferably consists of the chambers 48 and 49 forming pressure stages from which any air entering therein from the outside is sucked off by the pumps 40 and 51. This airtight duct has the advantage that it does not require any packing means which might be quickly destroyed by the high temperature of the metal bar 46 which it still has despite being cooled by the cooling system 45. Underneath the duct 47 the metal bar 46 is gripped by feed rollers 52 which are driven by a motor 53 and draw the metal bar downwardly.

The operation of the apparatus according to FIGURE 2 is as follows:

Before the apparatus is started, a suitable draw rod which at first takes the place of the metal rod 46 to be cast is inserted from below through the feed rollers 52 and duct 47 into the vacuum chamber 10 and then into the continuous-casting mold 45 so as to extend from the feed rollers to a point near the center of the length of mold 45. The ladle 40 is then raised so far that the end

of the section 26 of the intake pipe is immersed in the molten metal 20. Thereupon the valves 2 and 8 are opened and the pumps 3, 50, and 51 are started so as to evacuate the chambers 1 and 10 to the extent necessary to draw the molten metal from the ladle 40 to the level *h* in the degassing chamber 1.

The gas supply to the gas line 30 is then started and regulated so that the molten metal will not as yet flow over the hump 9 into the outlet pipe 6. When the casting process is to be started, a further supply of gas is passed through the gas line 31 into the intake pipe and the molten metal therein. This causes the metal to rise beyond the level *h* and to flow over the hump 9 and through the outlet pipe 6 into the mold 45 and upon the upper end surface of the draw rod which is then gradually lowered by the feed rollers 52 as the casting process proceeds and which is eventually replaced by the metal rod 46 when the latter has reached a sufficient length to be gripped by the feed rollers 52. The amount of gas which is supplied through the second gas line 31 as well as the rate of speed at which the metal rod 46 is withdrawn from chamber 10 by means of the feed rollers 52 are regulated in accordance with the rate at which the metal solidifies in the mold 45. Most important for the purposes of the invention is, however, the provision of suitable means for accurately regulating the increased rate of feed of gas, that is, the amount of gas which is to be fed into the molten metal in the intake line 4 beyond that at which the level of the metal in the degassing chamber 1 is slightly below or at least even with the tip of the hump 9. By such a control of the gas supply it is possible to regulate and control the casting rate and the quantity of metal to be cast in an extremely simple and accurate manner.

Although my invention has been illustrated and described with reference to the preferred embodiments thereof, I wish to have it understood that it is in no way limited to the details of such embodiments, but is capable of numerous modifications within the scope of the appended claims.

Having thus fully disclosed my invention, what I claim is:

1. A method of vacuum degassing and continuously casting molten metal, especially steel, into at least one mold, comprising the steps of inserting the lower end of the intake pipe of a degassing vessel into the molten metal, *said degassing vessel forming a vacuum siphon and containing said mold exposed to the vacuum*, evacuating said vessel so that said metal will rise in the intake pipe to a level *below* the upper end of said intake pipe but without flowing through said vessel into the outlet pipe *of said siphon, the upper end of said intake pipe having an overflow barrier*, feeding at least one gas into said intake pipe and into the molten metal therein at least at one point spaced from said *level of the metal* in said intake pipe, *and permitting the flow of said gas to raise* the level of said metal so that the metal will then flow *at a desired flow rate* through said vessel *and over said overflow barrier* to said outlet pipe and will thereby be degassed, and will then flow through said outlet pipe into said mold *at a controlled flow rate*.

2. A method as defined in claim 1, including further the step of reducing the rate of flow of said gas fed into the intake pipe to lower thereby the level of the metal, so that the overflow of metal from the intake to the outlet pipe and into said mold is stopped when said mold is substantially filled.

3. A method as defined in claim 1, further comprising the steps of reducing the rate of flow of gas fed into the intake pipe to the amount of gas fed into said pipe prior to the casting process when said mold is substantially filled, then moving said filled mold within said evacuated chamber from its position underneath said outlet pipe and replacing it by an empty mold without access of air during the mold-changing step, and then again increasing the rate of flow of gas fed into the intake pipe to start the next casting process.

4. A method of continuously degassing and continuously casting molten metal, especially steel, in a vacuum, comprising the steps of inserting the lower end of the intake pipe of a degassing vessel forming a vacuum siphon into the molten metal, evacuating said vessel as well as a vacuum chamber containing a continuous-casting mold and communicating with said vessel through the outlet pipe of said vessel, whereby said metal will rise in the intake pipe of said vessel to a level at least near the upper end of said intake pipe, then feeding a controlled amount of at least one gas into said intake pipe and the molten metal therein at least at one point spaced from said upper end of said intake pipe so as to lift said metal sufficiently to flow continuously through said vessel into said outlet pipe and thereby degassing said metal, and then casting said metal continuously from said outlet pipe into said mold, said mold having a temporary slidable bottom extending airtight from the lower end of said mold and from said evacuated chamber to the outside, lowering said bottom while the metal is first being cast into said mold and until the first-cast metal has solidified into a bar and said bar has started to slide airtight from said mold and said chamber to the outside, and then removing said bottom to permit said bar to move downwardly while being continuously cast at its upper end, and regulating the rate of feed of gas into said intake pipe and thereby regulating and controlling the casting process.

5. A method as defined in claim 4, in which, when the continuous casting process is to be interrupted, the rate of feed of gas into said intake pipe is reduced so as to stop the overflow of the molten metal from the upper end of the intake pipe through the degassing vessel to the outlet pipe thereof.

6. A method of degassing, and continuously casting metal, especially steel, in a vacuum, comprising the steps of producing a molten metal in a furnace, inserting the lower end of the intake pipe of a degassing vessel forming a vacuum siphon into said molten metal contained in a part of said furnace, evacuating said vessel as well as a vacuum chamber containing at least one mold and communicating with said vessel through the outlet pipe of said vessel, whereby said metal will rise in the intake pipe to a level at least near the upper end of said intake pipe, then feeding into said intake pipe at least at one lower point thereof and thus into the molten metal therein at least one gas at a constant rate, said gas being capable of reacting with at least one component of said metal, feeding into said intake pipe at a higher point thereof an inert gas at a fixed rate for lifting the metal into the degassing vessel but only to a level at which, due to the shape of said vessel, the metal cannot flow into said outlet pipe, and, when a casting process is to be started, increasing the rate of feed of said inert gas into said intake pipe so as to raise the level of said metal within the degassing vessel so that the metal will flow through said vessel and will thereby be degassed, and will then flow through said outlet pipe into said mold in said vacuum chamber, regulating said increased rate of feed and thereby regulating and controlling the casting process, and finally removing the cast metal from said vacuum chamber after being solidified therein, so that said metal remains without access of air from the furnace until removed from the apparatus as a solid body.

7. An apparatus for degassing and continuously casting molten metal, especially steel, in a vacuum, comprising a degassing vessel forming a vacuum siphon and having an intake pipe and an outlet pipe spaced from each other extending downwardly from said vessel, the lower end of said intake pipe adapted to be immersed into a molten metal, a vacuum chamber connected to said outlet pipe, at least one mold in said vacuum chamber underneath the lower end of said outlet pipe, means for evacu-

ating said degassing vessel and said vacuum chamber and for thereby lifting said metal in said intake pipe to a level at least near the upper end thereof, means for feeding into a lower part of said intake pipe and the molten metal therein at least one gas capable of reacting with at least one component of the metal and at a constant rate of feed, means for feeding an inert gas into a higher part of said intake pipe but at a point spaced from the upper end thereof, and means for controlling the rate of feed of said inert gas into said intake pipe so that prior to a casting process and when a casting process is to be interrupted a fixed minimum amount of inert gas is continuously fed into said intake pipe which is insufficient to lift the metal to a level within said degassing vessel at which the metal can run into said outlet pipe, and so that, when a casting process is to be carried out, the rate of feed of said inert gas is increased to raise the level of the metal in said degassing vessel so that the metal will flow continuously through said vessel to said outlet pipe and through said outlet pipe into said mold, said feed control means also being adapted to vary the increased rate of feed of said inert gas for thereby regulating and controlling the casting process, whereby said metal is degassed in said degassing chamber, said outlet pipe, said vacuum chamber, and said mold until solidified in said mold.

8. An apparatus as defined in claim **7**, further comprising means for supporting a plurality of molds in said vacuum chamber, and means controlled from the outside of said apparatus for moving said supporting means within said vacuum chamber so as to remove a filled mold from its position underneath said outlet pipe and to replace it by an empty mold while said chamber remains under the vacuum produced by said evacuating means.

9. An apparatus as defined in claim **7**, in which said mold in said vacuum chamber comprises a continuous-casting mold open at its upper and lower ends, water-cooling means for cooling said mold, said vacuum chamber having an outlet duct on its lower end for passing a metal bar cast in said mold out of said vacuum chamber, and means for hermetically sealing said duct relative to said metal bar.

10. An apparatus as defined in claim **9**, wherein said sealing means comprise at least two pressure-stage chambers on the lower side of said vacuum chamber and having coaxial openings connecting said chambers with each other, with said duct, and with the outside for passing said metal bar from said vacuum chamber to the outside, and at least one pump unit for evacuating said pressure-stage chambers while said metal bar is sliding therethrough.

11. A method of degassing and casting molten metal, especially steel, in a vacuum, comprising the steps of inserting the lower end of the intake pipe of a degassing vessel forming a vacuum siphon into the molten metal, evacuating said vessel as well as a vacuum chamber containing at least one mold and communicating with said vessel through the outlet pipe of said vessel, whereby said metal will rise in the intake pipe to a level at least near the upper end of said intake pipe, then feeding a controlled amount of at least one gas into said intake pipe and the molten metal therein at least at one point spaced from said upper end of said intake pipe so as to lift said metal, but only to a level within said degassing vessel at which, due to the shape of said vessel, the metal cannot flow into said outlet pipe, then increasing the rate of feed of gas into said intake pipe and thereby raising the level of said metal within said degassing vessel so that the metal will then flow through said vessel and will thereby be degassed and will then flow through said outlet pipe into said mold in said evacuated chamber to start the casting process, and regulating said increased feeding of the gas into said intake pipe and thereby regulating and controlling the casting process reducing the rate of feed of gas into the intake pipe to the amount of gas fed into said pipe prior to the casting process when said mold is substantially filled, then moving said filled mold within said evacuated chamber from its position underneath said outlet pipe and replacing it by an empty mold without access of air during the mold-changing step, and then again increasing the rate of feed of gas into the intake pipe to start the next casting process.

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J. SPENCER OVERHOLSER, *Primary Examiner.*

V. K. RISING, *Assistant Examiner.*