March 17, 1964 J. N. HORNAK ETAL 3,125,440

METHOD AND APPARATUS FOR TEEMING MOLTEN METAL

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FIG. 1

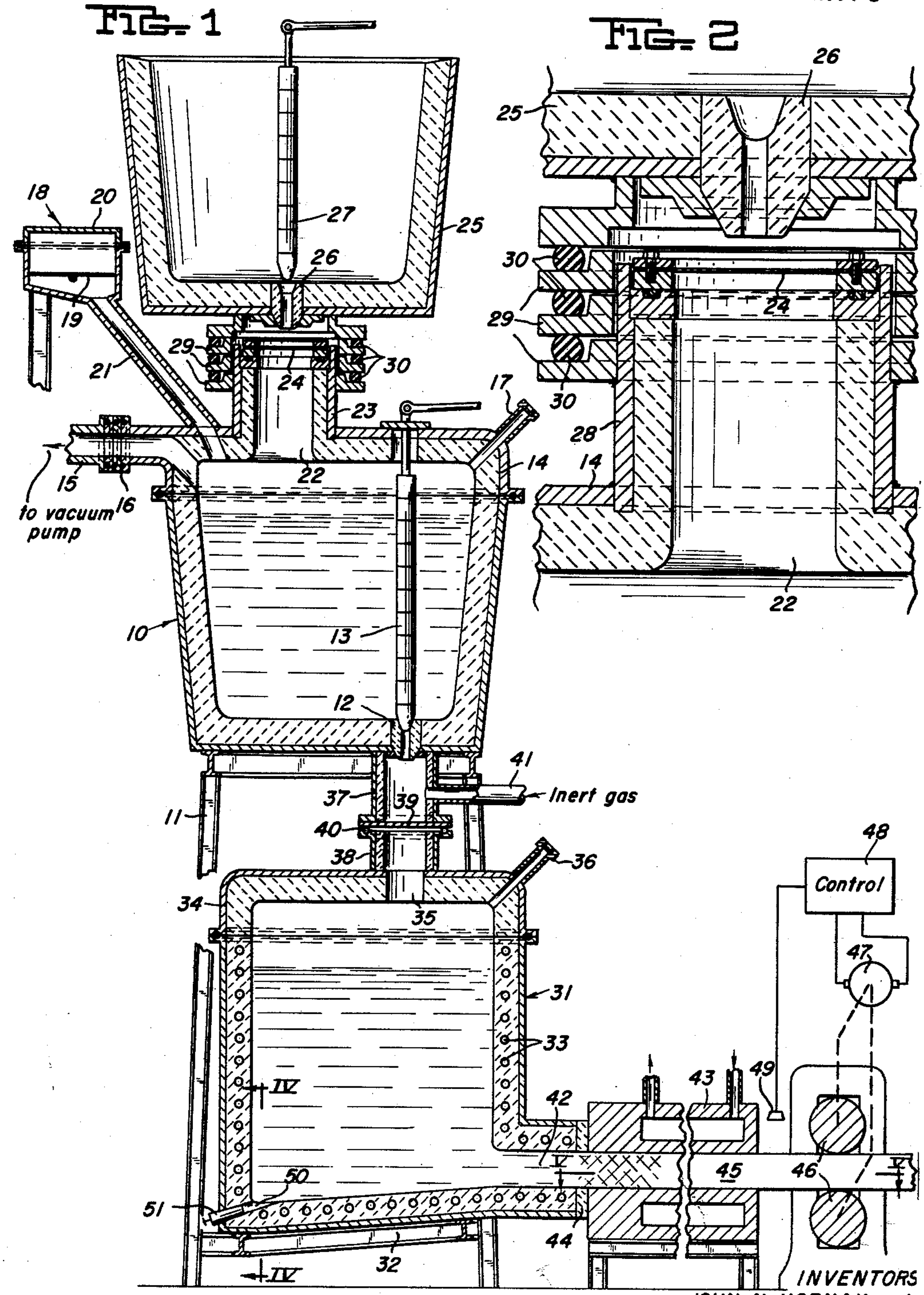

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FIG. 4

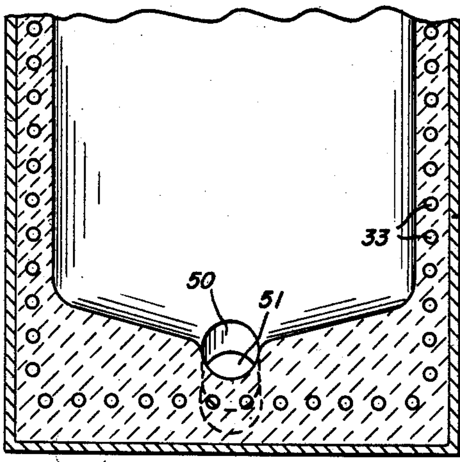


FIG. 3

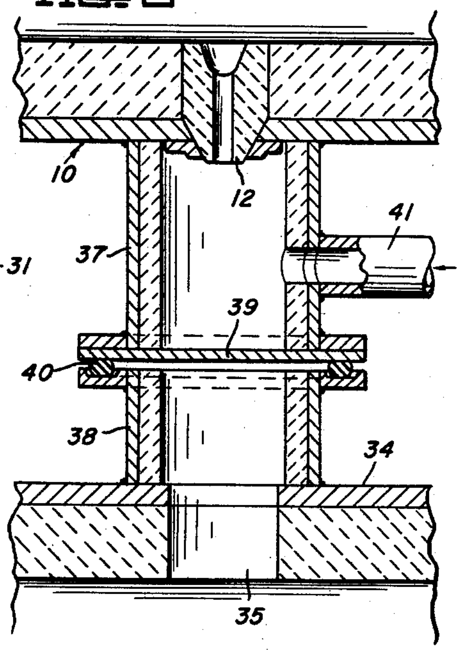
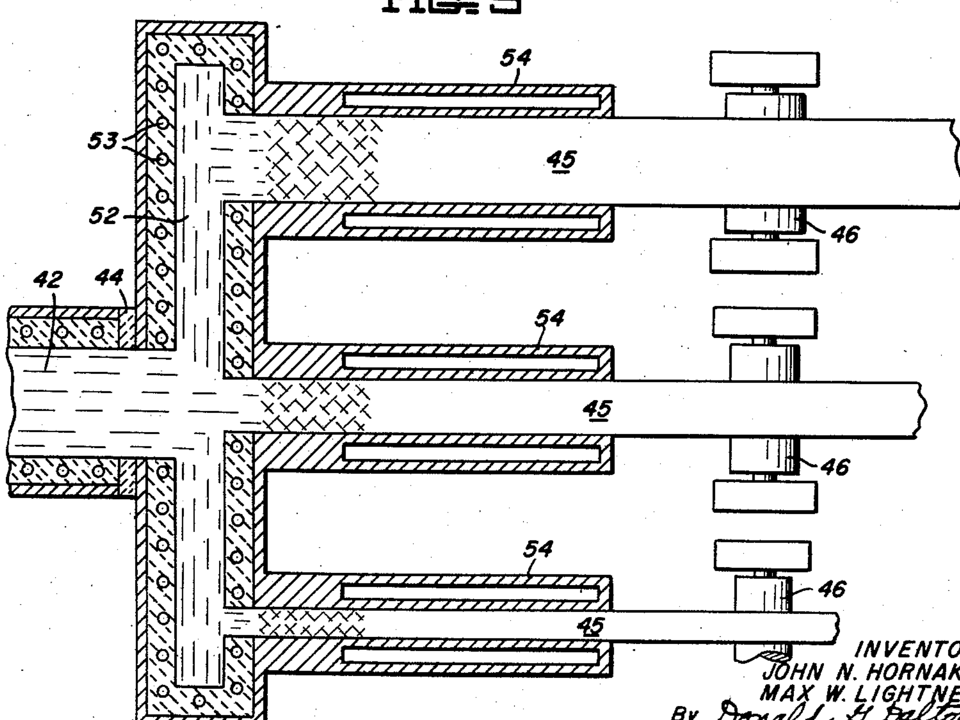


FIG. 5



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METHOD AND APPARATUS FOR TEEMING MOLTEN METAL

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This invention relates to a method and apparatus for converting molten metal such as liquid steel into semi-finished products such as billets and slabs.

It is the object of the invention to produce semi-finished steel characterized by a lower incidence of surface and internal defects than has been attainable heretofore by conventional methods. Attempts have been made to reduce the occurrence of certain types of defects but have led to an increase in defects of other types. Our invention not only reduces the occurrence of defects generally but also increases the product yield.

Our method comprises pouring liquid metal from a transport ladle first into a vacuum degassing chamber maintained at low pressure and then, after making the desired alloy additions thereto, into a stationary pouring vessel. From a side port in this vessel, metal emerges through a generally horizontal, water-cooled tubular mold, thereby forming one or more shaped masses continuous in length so long as a supply of molten metal is maintained in the vessel. These masses may be cut into the desired lengths for finish rolling.

A complete understanding of the invention may be obtained from the following detailed description and explanation which refer to the accompanying drawings illustrating the present preferred embodiment. In the drawings:

FIGURE 1 is a diagrammatic central vertical section through the apparatus of our invention;

FIGURES 2 and 3 are portions of FIGURE 1 to an enlarged scale; and

FIGURES 4 and 5 are partial sections taken along the planes of lines IV—IV and V—V, respectively, of FIGURE 1, the latter showing a modification.

Referring now in detail to the drawings and, for the present, particularly to FIGURE 1, we provide a vacuum degassing chamber 1 removably mounted on a supporting frame 11 a suitable distance above floor level. The chamber is generally similar to a ladle in that it is a refractory-lined vessel of metal plate, and has a bottom pouring spout 12 as well as a conventional stopper 13. In addition, the chamber has a removable top 14 with adequate sealing means to permit the establishment by evacuation of a low absolute pressure, such as 100 microns of mercury, in the chamber. To this end an exhaust pipe 15 extends from the cover to a suitable vacuum pump. The pipe is fitted with a detachable connection 16 to be described in detail later.

The cover also has a sight tube 17 fitted thereto and a charging box 18 for alloy additions. Box 18 has a tilting plate 19 therein and a removable, vacuum-tight cover 20. On tilting of the plate by means accessible on the exterior of the box, a charge of alloy addition placed thereon while the cover is removed, is permitted to slide down chute 21 connecting the box to top 14. The top also has an inlet port 22 therein from which a neck 23 extends upwardly. A seal plate 24 of metal such as aluminum, on top of the neck closes the port 22 during evacuation.

Neck 23 is adapted to support a conventional refractory-lined, bottom-pour transport ladle 25 when placed thereon with its spout 26 centered in the neck. The ladle

has a conventional stopper indicated at 27. As shown in FIGURE 2, the neck comprises a refractory-lined pipe 28 welded to cover 14 and a stack of metal rings 29 each having a circumferential shoulder or flange adapted to receive a compressible seal ring 30 of rubber or like material. The bottom ring 29 is welded to pipe 28 and the remaining rings are loose thereon. Rings 30 are compressed by the weight of ladle 25 and its contents and thus effect a vacuum-tight seal between rings 29 as they come into bearing contact with each other. This sealing structure is also described and claimed in Patent 3,091,265 of Clarence P. Ulstad, dated May 28, 1963. Connection 16 is similar to neck 23 but has suitable clamping means, e.g., bolts, for rendering the seals effective.

Reverting to FIGURE 1, a pouring vessel 31 is supported below chamber 10 on a frame 32. Vessel 31 is a refractory-lined metal plate structure with a heating coil 33 embedded in the lining. The coil may be an electric-resistance or induction coil or a tube for the passage of hot combustion gases. The vessel 31 has a removable top 34 thereon provided with an inlet port 35 alined with spout 12 and a sight tube 36. A refractory-lined nozzle pipe 37 extends downwardly from chamber 10 for mating with a refractory-lined inlet pipe 38 upstanding on top 34, as best shown in FIGURE 3. A plate 39 of aluminum is secured to the bottom of pipe 37 to close it during evacuation of chamber 10. A compressible ring 40 forms a gas-tight seal betwen pipes 37 and 38 when chamber 10 is disposed on its supporting frame. A valved gas-supply pipe 41 extends laterally from pipe 37.

Vessel 31 has an outlet port 42 on one side adjacent the bottom. A tubular water-cooled mold 43 is positioned generally horizontally to receive metal from port 42. A spacer ring 44 of thermal insulation is placed between the port and the mold. A starting bar 45 closes the mold prior to the beginning of operations. Pinch rolls 46 driven by a motor 47 serve to move the bar horizontally and draw out a continuous casting of metal from vessel 31 which is shaped and frozen at least on the exterior, on passing through the mold. Motor 47 is controlled by a device 48 in accord with the signal from a radiation-sensitive cell 49, focused on the issuing casting.

The bottom of vessel 31 slopes toward the center as shown in FIGURE 4 and also away from port 42 toward a drain outlet 50. Thus when the level of the metal in the vessel is too low for continued pouring, the balance may be drained by removal of a refractory plug 51 in outlet 50 to prevent formation of a skull.

Mold 43 may have a single cavity or passage, but for greater production, we may use the arrangement of FIGURE 5 wherein a refractory-lined header 52, with a heating coil 53 embedded in the lining thereof, receives liquid metal from outlet 42 and conducts it to a plurality of water-cooled molds 54. The latter may be all alike or of different sizes and shapes.

The method of our invention will become apparent from the following explanation of the utilization of the apparatus described above. At the start of a pour, ladle 25 is removed to receive a heat of steel made in any convenient melting furnace without the usual addition of ferro-alloys, deoxidizers, etc. In the meantime, plates 24 and 39 are installed, the desired alloy additions are placed on plate 19, cover 20 is tightened down and the vacuum pump is operated to reduce the absolute pressure in chamber 10 to, say 100 microns of mercury. When this condition has been attained, the filled ladle is carefully placed on neck 23. Stopper 27 is then raised and the liquid steel flows into the neck 23, fuses plate 24 and starts to fill chamber 10.

Because of the low absolute pressure existing in chamber 10, the entering stream forms a spray. As a result, gases dissolved in the steel are evolved and escape through pipe **15**. When degassing has been completed, plate **19** is tilted to make the necessary addition of ferroalloys. In order to cause the turbulence needed for thorough distribution of the additions, inert gas such as argon may be admitted under the requisite pressure through pipe **41** to pipe **37** and thence into the molten metal in chamber **10** by cracking stopper **13**. After the additions have had time to fuse, stopper **13** is opened fully and steel flows through pipe **37**, melts plate **39**, and then flows through pipe **38**. It then enters into outlet **42** and rises in vessel **31**, filling it to a predetermined level. Gas supplied through pipe **41** maintains an inert atmosphere above the surface of the metal.

As an alternative method of making the necessary additions to the bath, the additions could be finely divided, fluidized by proper means, and conveyed into the bath by means of a gas stream passing through a lance inserted through the vacuum-tank cover **14**. In this method of making the additions, the gas passing through the lance must not be reactive with the metal in the bath.

When the metal has risen in vessel **31** to provide sufficient ferrostatic head to overcome atmospheric pressure, and preferably a greater amount, e.g., 2 atmospheres, pinch rolls **46** are started to extract bar **45** and start a casting through the mold **43**. After passing the pinch rolls **46**, the casting may be sent through a stand of rolls (not shown) suitable to effect a slight reduction in section and then, after solidification, which may be aided by water sprays, cut into the desired lengths.

Our invention has the advantage that it substantially reduces the incidence of surface and internal defects in semi-finished steel. Another advantage is an increase in yield per ton of molten metal. By making alloy additions in the degassing chamber and only after the steel has been degassed, instead of in the furnace, we avoid the dirty steel sometimes resulting from furnace additions. Instead of the latter, when the amounts of the residual elements (sulphur and phosphorus) have been sufficiently reduced, we tap the heat without additions into the ladle. The carbon content of the bath, however, for reasons which will be explained later, must be slightly greater than that specificed for the order. With no bath additions, the oxygen concentration of the metal as it leaves the furnace is at its maximum or equilibrium level, and for this reason, oxidation of the stream is not encountered during the tapping operation. Such is not the case when the metal is deoxidized by a bath addition, as in present commercial practices. Because the steel is not reoxidized during the tapping operation, it retains its high degree of cleanliness going into the ladle **25** and its high state of oxidation which if additions were made to the ladle, could produce a dirty steel. We thus achieve improved results by making the alloy additions to the metal not in the steel ladle but in the degassing chamber.

At the pressure under which steel enters chamber **10**, carbon reacts more readily with oxygen than aluminum does. Also the carbon-oxygen reaction generates a gas, which is exhausted to the atmosphere by the vacuum pump. Because of the low pressure and the violent turbulence set up by the carbon-oxygen reaction, the nitrogen and the hydrogen contained in the steel are also reduced to very low levels, hydrogen to about 1 p.p.m. and nitrogen to 20 p.p.m. or less. The oxygen level under these conditions is reduced to less than 100 p.p.m. In the reaction, some carbon is eliminated from the metal and for this reason, as previously stated, the carbon content of the bath at tap should be higher than called for by the specification. Because steel containing about 1 p.p.m. of hydrogen is insensitive to flaking and because the product of deoxidation is a gas that is discharged to the atmosphere, the degassing operation described eliminates two sources of difficulty (flaking and unsatisfactory micro-cleanliness) in producing acceptable product. Reducing the oxygen concentration in the steel to 100 p.p.m. or less has another benefit in that the efficiency of the additions is increased.

For the successful operation of the process it is necessary that the temperature of the zone just ahead of the mold be maintained above the melting point of the steel being processed. Unless this temperature level is maintained, skulling or freezing of the metal can occur, and tearing of the cast section will result. It is critical that freezing of the metal take place in the mold only and not in the vessel **31**, especially in the outlet **42** just ahead of the mold.

Producing semi-finished or finished product by our method eliminates several sources of difficulty that are encountered with normal processing procedures. By maintaining an inert atmosphere in the vessel **31**, we avoid exposing the treated steel to an oxidizing atmosphere, such as the atmosphere surrounding steel being cast into ingots by conventional procedures. This eliminates a potential source of dirty steel. This direct conversion of liquid steel to finished or semi-finished product also eliminates other sources of difficulties, such as slivers and scabs resulting from sloppy pouring of ingots, or from the use of molds with a rough or defective surface; cracks resulting from the long delivery of air-hardening steel; and burnt steel resulting from overheating of ingots in preparation for rolling.

In addition, steel is normally produced to one of three practices, that is, killed, semi-killed, or open steel, the open steels being rimmed or capped. To produce steel to each of these three classifications requires a different and critical control in normal processing if acceptable product is to be obtained. With our invention, no difference in melting practice is required. The reason for this is that the gas concentration of the steel is reduced to a low uniform level in the chamber **10**. This is possible because subsequent handling and steel structure are not dependent on controlling the gas concentrations in the metal to obtain acceptable product and high metal yields.

Also, with our practice, the liquid steel, as it chills to form a solid section in the mold, will have no pipe cavity, because a ferrostatic head of liquid metal prevails at all times and forces liquid metal into the center of the solidifying section. In other words, the process has built into it what amounts to a continuous hot-topping operation. Because of the low gas content and the continuous hot-topping action, normal difficulties that fall into the categories of micro-cleanliness, pipe and center porosity, and segregation are reduced. Finally, if from 10 to 25% reduction of the section is performed by a second set of rolls, center porosity is eliminated.

This additional rolling is preferably done when about 90% of the ingot has solidified. For example, with an ingot 8 inches square in cross section, the depth to which the ingot has solidified should be about 3.6 inches when the additional rolling is done. The depth of solidification may be predicted in general from the equation $D=\sqrt{T}$, where D is the depth to which the ingot has solidified in inches and T is the time in minutes from the starting of solidification. From this equation and a knowledge of the casting rate, it is possible to position the additional roll stand properly; alternatively, for a given position of the roll stand, the casting rate may be controlled so that the rolling is done when the ingot has solidified to the depth desired.

Although we have disclosed herein the preferred embodiment of our invention, we intend to cover as well any change or modification therein which may be made without departing from the spirit and scope of the invention.

We claim:

1. A method of degassing steel in a closed vacuum chamber having a top inlet and a stoppered bottom outlet, which comprises placing alloy additions in an enclosure communicating with said chamber, evacuating the

chamber, placing on the chamber a ladle having a bottom outlet and containing molten steel of a higher carbon content than that desired in the final product, sealing the ladle outlet to the chamber inlet, teeming steel from said ladle into said chamber, holding the steel in the chamber for the time necessary to effect carbon deoxidation of the steel, then releasing said alloy additions from said enclosure into the steel in said chamber while maintaining a high vacuum therein, cracking the stopper in the chamber outlet, draining steel into a pouring vessel through a pipe connecting said chamber to said vessel and admitting inert gas under pressure to said pipe.

2. Apparatus for teeming molten metal comprising

a pouring vessel having a removable cover, a bottom outlet and a top inlet,

a closed degassing chamber above said vessel having a removable cover, a bottom outlet detachably connectible to said pouring-vessel inlet and a top inlet engageable by the bottom outlet of a transport ladle,

a box above said chamber for holding alloy additions,

and a chute extending from said box through the top of said chamber,

the inlet of said chamber having a gas-tight seal adapted to be engaged by the outlet of said ladle when lowered thereon,

and an exhaust pipe connected to said chamber.

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