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 [21] Appl. No. **731,017**
 [22] Filed **May 22, 1968**
 [45] Patented **June 28, 1971**

[54] **CONTINUOUS CASTING APPARATUS**
 12 Claims, 9 Drawing Figs.

[52] U.S. Cl. **164/281,**
 164/82
 [51] Int. Cl. **B22d 11/10**
 [50] Field of Search 164/50, 73,
 82, 122, 133, 155, 268, 273, 281, 283, 337

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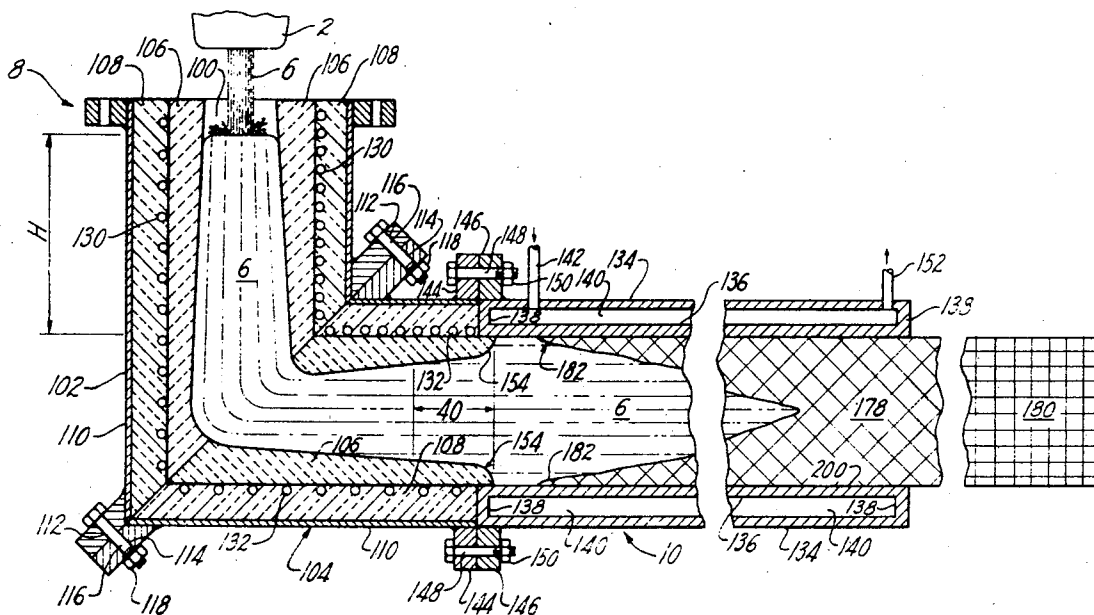
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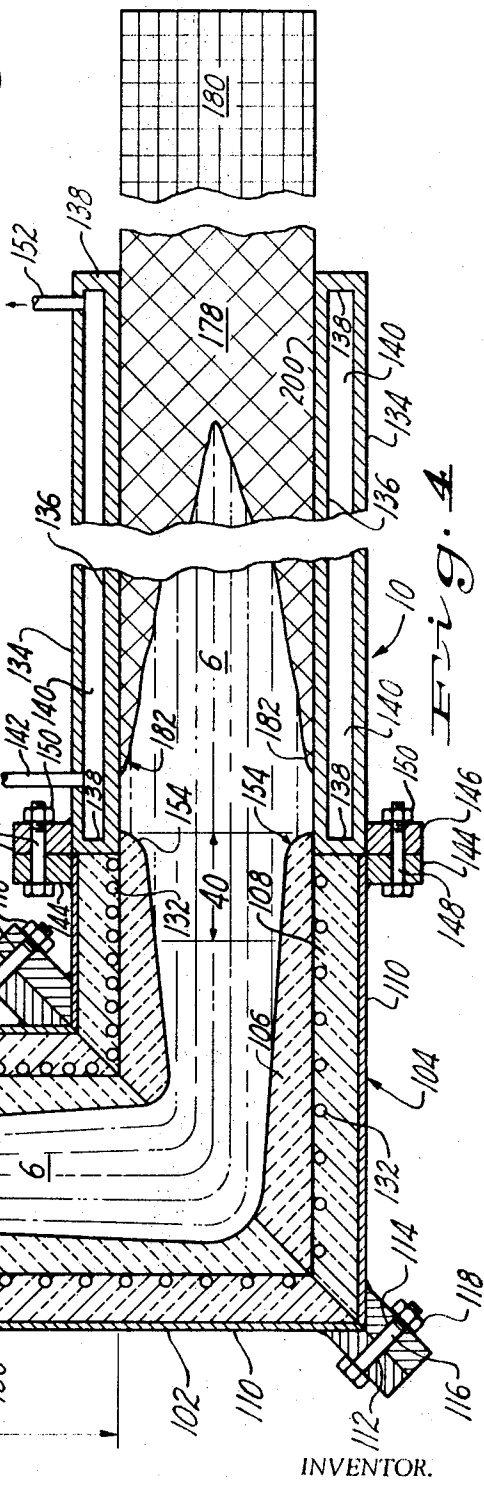
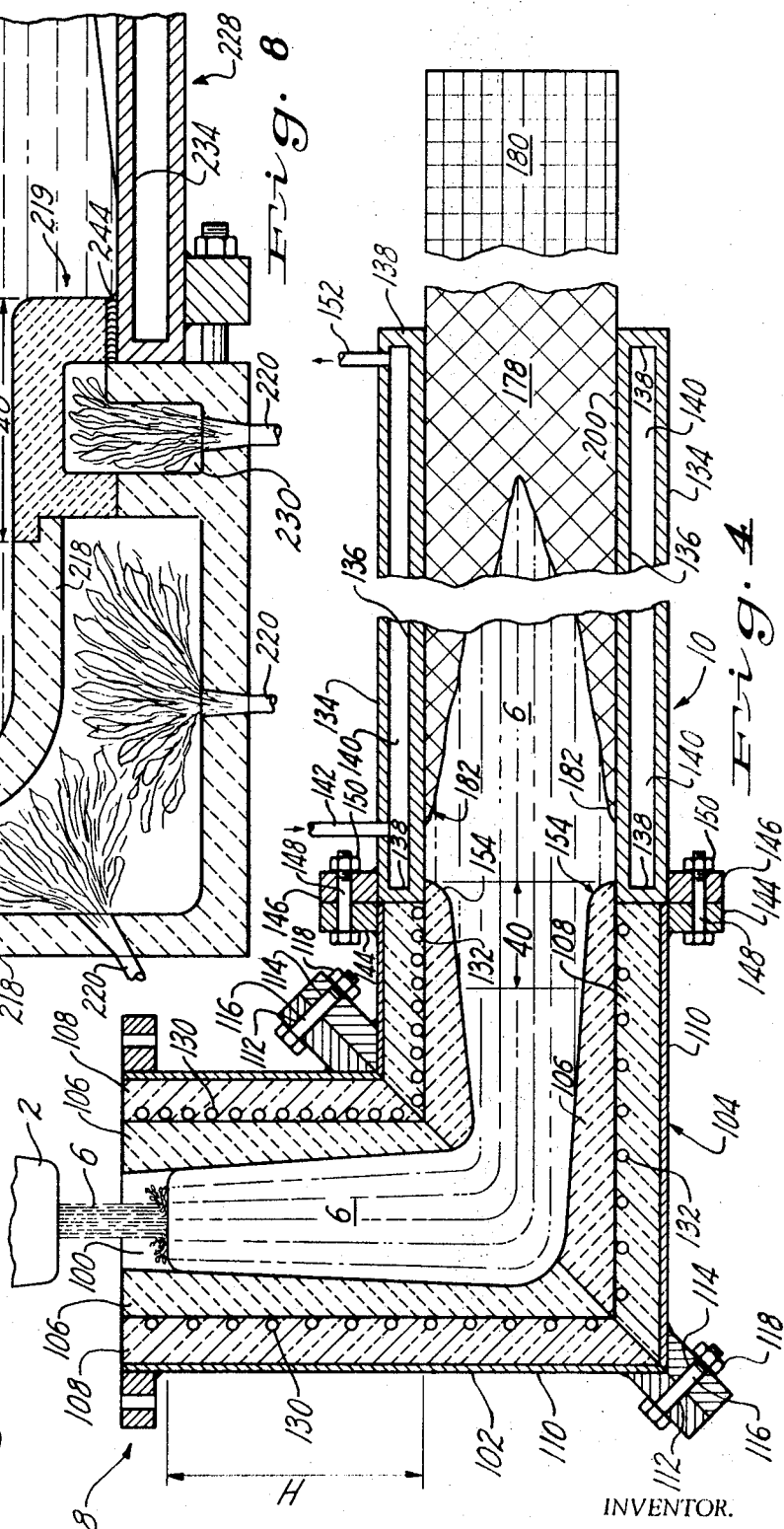
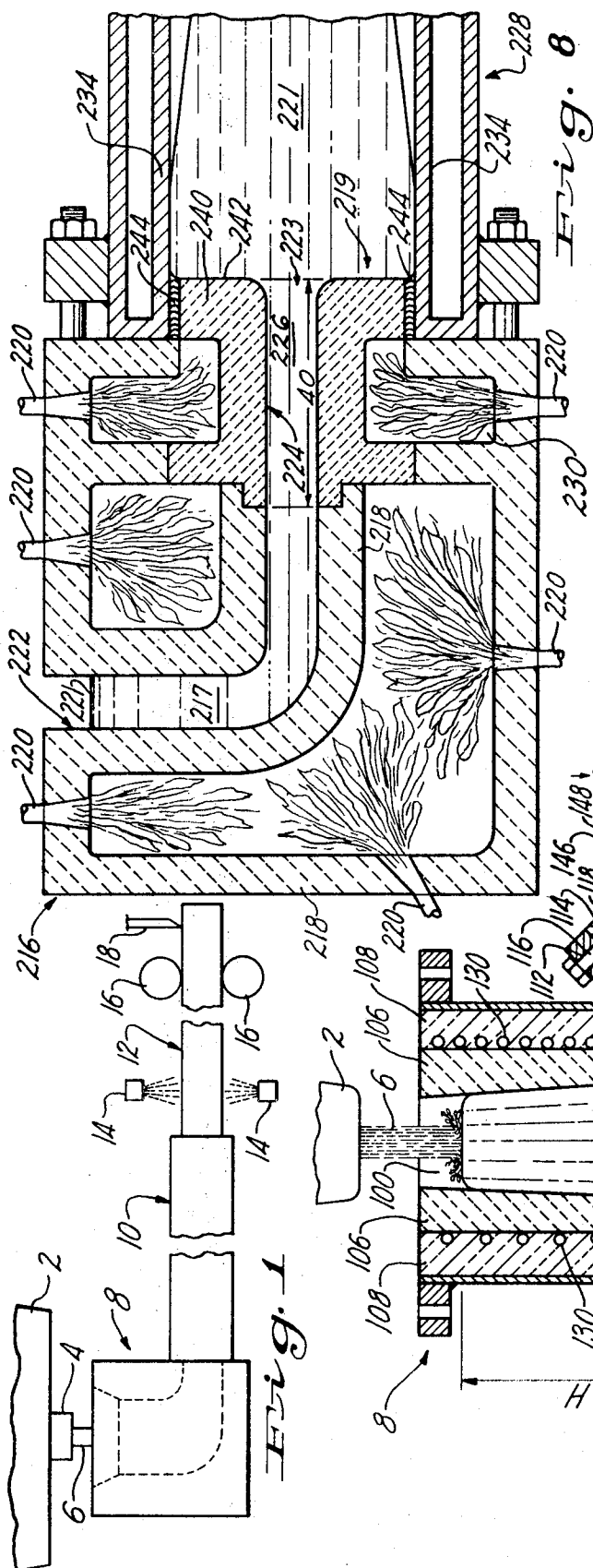
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ABSTRACT: Apparatus for continuous casting of metals, having a nozzle with a charging section and a discharging sec-

tion. A liquid cooled continuous casting mold having an entry end and a discharge end. The nozzle has a molten metal receiving opening in a charging section and a molten metal discharge opening in the discharge section communicating with the entry end of the mold. The nozzle has a liner of refractory material and may also have an insulating material disposed externally of the refractory material. A heated zone disposed adjacent the discharge opening of the nozzle for preventing solidification of the molten metal within the zone. In one form, the heating means maintains the nozzle liner within the heated zone at no less than the melting temperature of the metal. The charging section of the nozzle may be heated to maintain flowability of the metal therethrough. Such an assembly wherein the nozzle liner may extend into the entry end of the mold or be abutted against the upstream end of the mold. The nozzle liner may have a portion of increased thermal conductivity within the heated zone relative to the remainder of the liner. The nozzle may terminate in a transverse heated wall abutting or extending into the mold. Sealing means, preferably having insulating properties, disposed intermediate the liner and the mold. Lubricating reservoirs disposed within the mold wall communicating with the mold interior. A method of continuous casting wherein a nozzle has charging and discharging sections with a heated zone within the discharge section. The discharge section is positioned to communicate with the entry end of the mold. Introducing a stream molten metal into the charging section of the nozzle, passing the stream of molten metal through the discharging section and into the mold. Continuously heating the nozzle in the heated zone in order to prevent solidification of the molten metal within this zone. The charging section may be heated to maintain flowability with or without some solidification therethrough. Passing completely molten metal to the mold for solidification initiated at a point within the mold longitudinally spaced from the nozzle.





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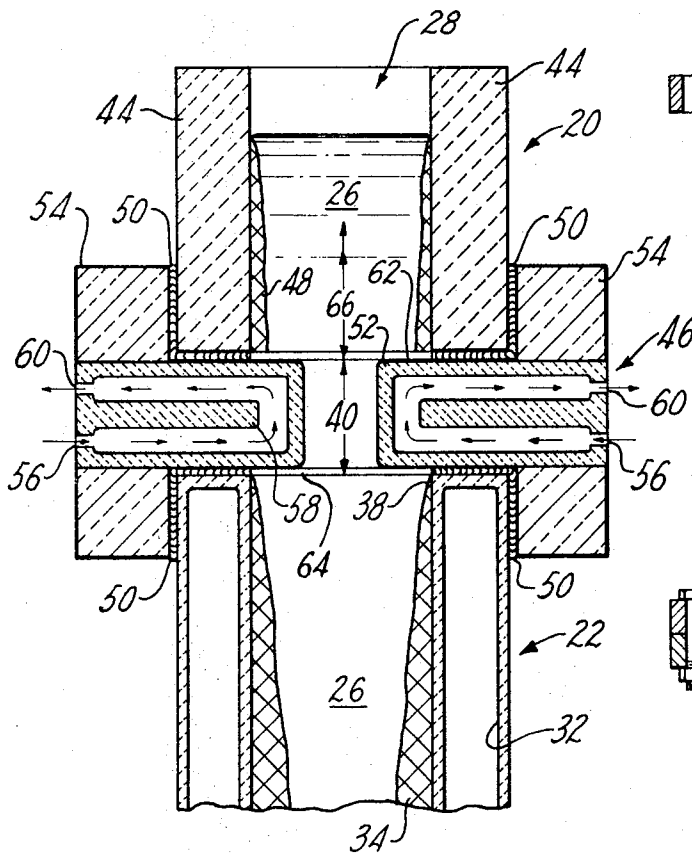


Fig. 3

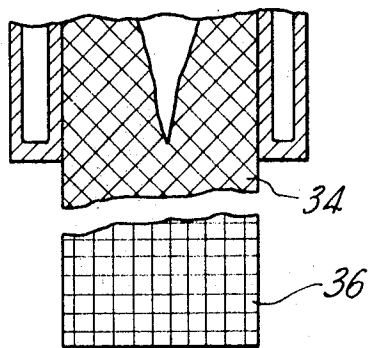
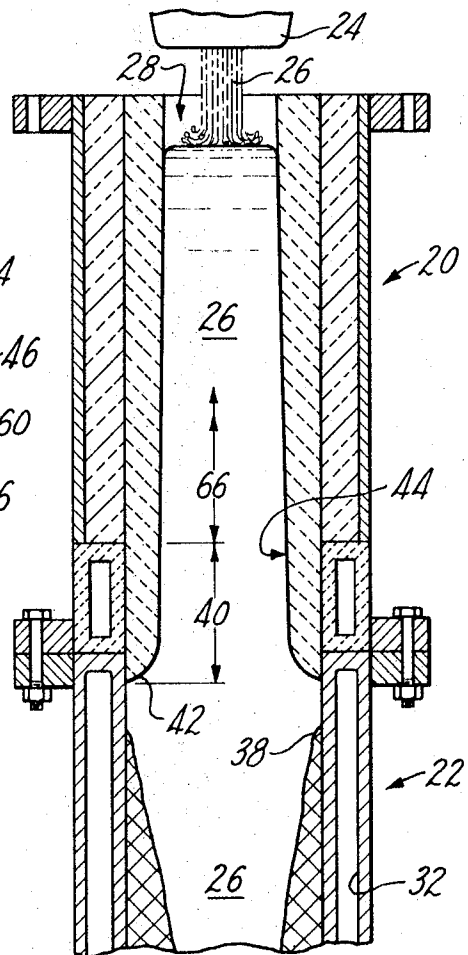


Fig. 2

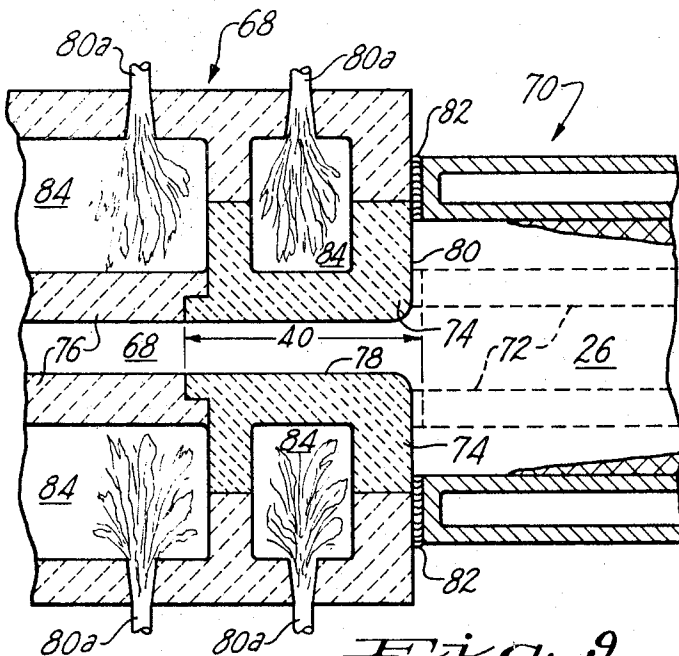


Fig. 9

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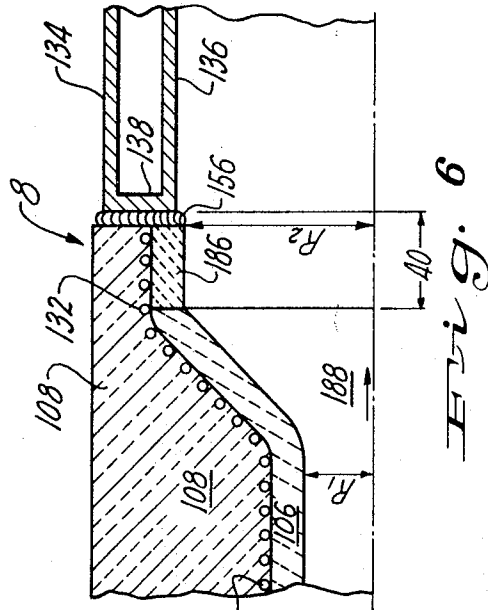


Fig. 6

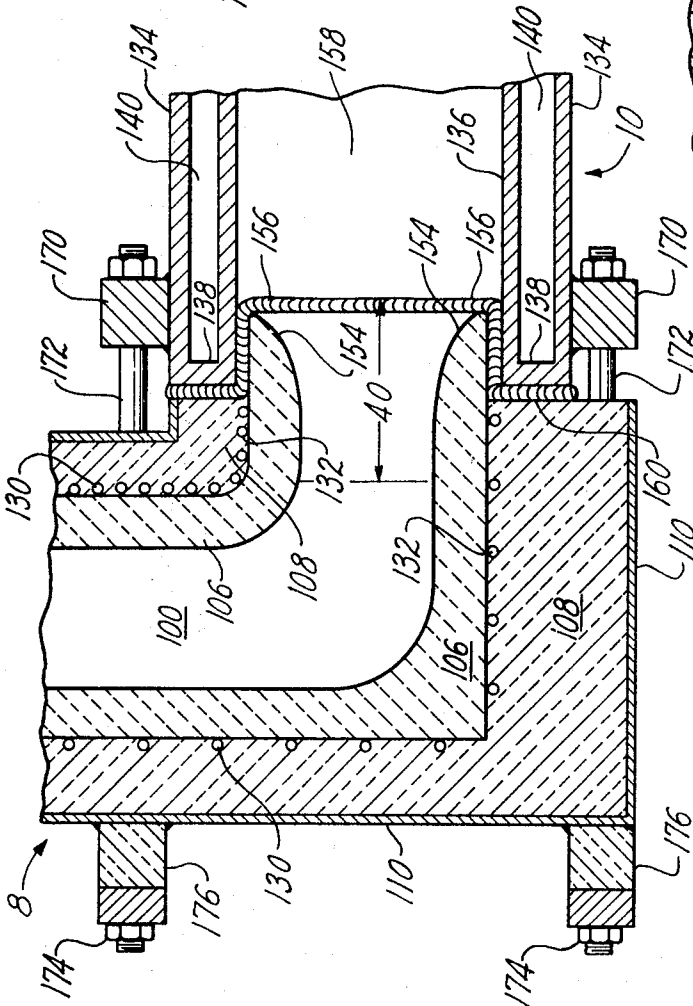


Fig. 5

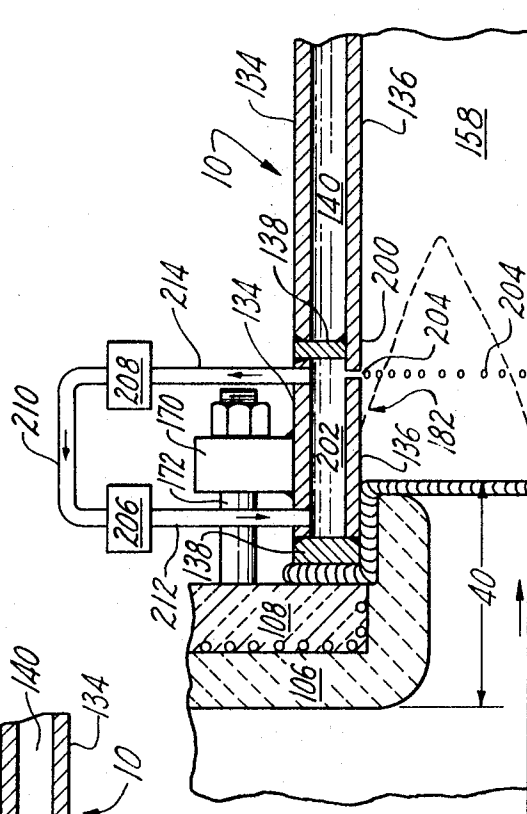


Fig. 7

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CONTINUOUS CASTING APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to apparatus and method for the continuous casting of molten metal employing a nozzle provided with heating means. More specifically, it relates to a system and method of continuously preventing any premature solidification of metal adjacent the nozzle discharge opening in order to eliminate the production of defective castings and also eliminate clogging of the passageway of the nozzle and the mold.

2. Description of the Prior Art

In conventional continuous metal casting practice, a reservoir of molten metal, such as a tundish is provided. The molten metal is directed from an opening in the reservoir into a jacketed mold which is generally water-cooled. During initial start-up, a dummy or starter billet is inserted into the discharge end of the mold in order to prevent the rapid flow of molten metal completely through the mold without adequate solidification. After solidification has been initiated at the discharge end of the mold, the dummy billet is removed. In operation of this apparatus, molten metal is introduced into the head or entry passage of the mold, heat is extracted from the molten metal as it passes through the mold in order to solidify the metal. The solidified billet is continuously withdrawn at the discharge end of the mold. In order to assist with continuous billet withdrawal, one or more pairs of pinch rolls disposed adjacent the discharge end of the mold are frequently provided. Also, in order to effect additional cooling, water may be sprayed on the billet as it emerges from the discharge end of the mold. Finally, cutting means, such as a flying shear or a torch, are provided in order to cut the billet to desired length after it has passed through the pinch rolls. Systems of this general type are described in U.S. Pat. Nos. 3,263,283; 2,837,791 and 3,286,309.

One of the major problems encountered with this type of casting apparatus is the difficulty of obtaining uniform high quality surface characteristics as well as a fine grain structure of the cast billets. This problem is particularly acute where the apparatus is employed in the continuous casting of ferrous metals as the operating temperatures tend to be substantially higher than for nonferrous metals. A related problem of equal importance has been the need to maintain effective control over the solidification rate of the molten metal so as to prevent the formation of undesired skin or skull through premature solidification. In addition to establishing defects in the billet, this skin tends to build up and create a restriction within the mold which causes hangup of the material within the mold. In some instances, this undesired buildup is accelerated by the prematurely formed skin contacting the solidifying metal within the mold. The result of such uncontrolled solidification is the production of defective billets and ultimate shutdown of casting operations for repairs.

One means of attempting to solve this problem has been through the use of mechanical reciprocation of the mold in an axial direction relative to the billet being formed.

In horizontal casting, the obvious disadvantage of such an arrangement resides not only in the need for suitable reciprocation machinery and mold mounting, but also in the resulting awkwardness of the arrangement, in view of the basic need to have a molten metal reservoir secured to and communicating with the mold. One means of avoiding this difficulty while employing mechanical reciprocation as an attempted solution has been suggested in U.S. Pat. No. 3,278,999. This patent discloses apparatus having a stationary mold and tundish. The pinch rolls are mounted for oscillating movement relative to the mold and reciprocation is established in this fashion.

Another suggested solution to the problem of continuously producing castings with the desired characteristics has been to employ a lubricant introduced into the mold in order to attempt to reduce adhesion between the mold surface and the solidifying metal. U.S. Pat. No. 3,286,309 discloses the in-

roduction of lubricant into a horizontal mold, at the entry end of the mold through grooves disposed between the mold and an adjacent refractory header. Similarly, U.S. Pat. No. 2,837,791 discloses lubricant introduced by means of a pipe passing through the outer and inner jacket-defining walls of the mold. The lubricant enters into a gap between the interior mold surface and the exterior surface of a nozzle inserted into the mold and ultimately passes into the mold through this gap.

A third approach to this problem has been to attempt to employ supplemental heating means in combination with a pressurized molten metal supply environment in order to control the extraction of heat from the molten metal prior to entry into the cold mold and to establish movement of the metal therethrough. U.S. Pat. No. 2,530,854 discloses a refractory-lined metal crucible housed in a pressurized vessel. A heating coil is disposed within the crucible wall and adapted to retain the metal in a molten state within the crucible. A refractory lined conduit receives molten metal through an opening in the bottom of the crucible and transports the metal to a cooling chamber. This conduit is also provided with heating coils. A substantial pressure generated within the pressurized vessel combines with the coils, which are employed to reduce the rate of solidification of the metal, to establish movement of the metal through the apparatus.

The above-mentioned means of improving the characteristics of the cast product and reducing hangup of the material within the mold are not mutually exclusive and numerous combinations of the use of mechanical reciprocation, lubrication, pressure chambers and hating have been attempted. In spite of this, there remains a substantial need for improved continuous casting systems which will eliminate the above-mentioned problems and provide significant improvements in the efficiency of such systems, as well as improved quality of the cast billets.

SUMMARY OF THE INVENTION

This invention provides apparatus and a method for effectively controlling the continuous casting operation so as to obtain efficient flow of metal and produce a superior cast billet or slab. The apparatus of this invention has a refractory lined nozzle with outwardly disposed insulating material adjacent the refractory liner. The apparatus is designed so as to eliminate the need for a tundish, where desired, and facilitate direct transfer of molten metal from a ladle into a nozzle. The nozzle has a charging section and a discharging section. A heated zone is provided within the nozzle liner adjacent the discharge opening of the discharge section to prevent solidification of the molten metal within the zone. The liner may be maintained at a sufficiently high temperature to prevent heat removal within the zone. The charging section of the nozzle may be heated in order to maintain molten metal flow therethrough with or without some solidification. The refractory liner has an extension which either extends into or abuts against a liquid-cooled mold. Sealing means prevent passage of molten metal between liner and mold and preferably serve as insulating means to help prevent premature solidification. The mean internal cross-sectional area of both sections of the nozzle are usually less than the mean cross-sectional area of the mold. Integral lubricant jackets may be provided within the mold and have ports communicating with the mold interior at a position downstream of the position at which initial solidification occurs. Also, a preferred form of the invention provides an improved refractory lining structure adapted to provide increased thermal transfer efficiency within the heated zone.

The method of this invention contemplates continuous heating of the nozzle liner in a heated zone adjacent the discharge opening of the nozzle to a temperature sufficient to prevent solidification or skin formation. This temperature may be at or above the melting point of the metal in order to remelt any previously solidified metal. This results in a sector of completely molten metal being produced adjacent the head of

the mold. The heating means are employed to eliminate or limit heat withdrawal from the metal within the nozzle heated zone and to establish either a temperature gradient directed inwardly toward the nozzle interior or to establish an equilibrium condition without heat flow between the nozzle liner and the molten metal. In one form of the invention, the temperature gradient across the heated zone is greater than that across the charging section. The temperature of the metal in the heated zone of the discharging section of the nozzle is elevated sufficiently high so that solidification of the metal within the mold occurs at a point spaced downstream from the head of the mold. This prevents any skin from being prematurely formed within the discharging section of the nozzle or remelts any skin previously formed.

It is an object of this invention to provide apparatus for the continuous casting of a metal which is adapted to provide effective thermal control of the metal temperature in order to provide efficient movement of the metal therethrough and reduce or eliminate the need for auxiliary metal flow assisting means such as mechanical mold reciprocation, lubrication and pressurized chambers.

It is another object of this invention to provide an insulated refractory nozzle adapted to receive molten metal directly from a ladle or tundish and transfer completely molten metal at its discharge end to the head end of a casting mold.

It is a further object of this invention to provide apparatus for continuous casting having a jacketed liquid cooled mold with jacket lubricant reservoirs communicating with the mold interior.

It is another object of this invention to provide apparatus for continuous casting having a sealed connection between the nozzle and the mold of such configuration as to facilitate effective transfer of molten metal to the mold without the formation of metal deposition deleterious to the production of a high quality metal casting.

It is another object of this invention to provide a method of continuous casting which provides continuous remelting of any prematurely solidified portions of the metal prior to introduction of metal into the mold.

It is yet another object of this invention to facilitate efficient flow of metal through the mold by means of thermal treatment of the molten metal prior to introduction into the mold.

Other objects and advantages of the invention will be understood from the following description of the invention, on reference to the illustrations appended hereto.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side elevational view, partly schematic, illustrating a type of horizontal continuous casting apparatus contemplated by this invention.

FIG. 2 is a sectional elevation of a type of vertical continuous casting apparatus contemplated by this invention.

FIG. 3 is similar to FIG. 2 but illustrates a particular type of heating means and metal solidification pattern.

FIG. 4 is a sectional elevation of a type of casting apparatus contemplated by this invention.

FIG. 5 is a fragmentary sectional elevation of a type of casting apparatus showing the sealing means employed between the nozzle and the mold.

FIG. 6 illustrates a modified form of nozzle structure having a compound refractory liner.

FIG. 7 is similar to FIG. 5 but illustrates partially schematically, mold lubricating means contemplated by this invention.

FIG. 8 illustrates a modified form of nozzle structure having a modified nozzle discharge design.

FIG. 9 is similar to FIG. 8 but shows another modified form of nozzle discharge design.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Turning now to the drawings in greater detail, FIG. 1 illustrates a type of continuous casting apparatus contemplated by this invention. A ladle 2 has a discharge outlet 4. A stream of

molten metal 6 flows from ladle 2 to nozzle 8. The molten metal 6 flows through nozzle 8 into liquid-cooled mold 10. Heat is extracted within mold 10 in order to solidify the molten metal 6 and cast billet 12, it passes through a spray of cooling water provided by sprayers 14 to effect a further reduction in temperature. A pair of driven rotating pinch rolls 16 engage opposed surfaces of billet 12 and pull the billet 12 from the mold 10. Cutting means having a flying shear 18 are provided.

Considering the apparatus illustrated in FIG. 2, one of the basic concepts of this invention is shown therein. The FIG. illustrates a nozzle 20 and a cooperating water-cooled mold 22 employed in a vertical continuous casting operation. A molten metal supply reservoir 24 supplies a stream of molten metal 26 to the charging opening 28 of the nozzle. The molten metal moves downwardly through the nozzle 20 emerges from the discharge opening 42 and enters the mold 22. The mold 22 has water-cooled jackets 32 which serve to assist in the withdrawal of heat from the molten metal 26 in order to establish initial solidified metal portion 34 which ultimately becomes billet 36.

As has been indicated above, it is essential to the efficient functioning of the continuous casting operation that the flow and solidification of the molten metal be effectively controlled. In this connection, it is important that premature freezing and the resultant buildup of prematurely solidified metal which might produce clogging of the nozzle passageway be eliminated. Also, it is important that solidifying metal, at the initial freezing point 38 within the mold, be kept out of contact with any prematurely frozen metal anywhere within the nozzle. The apparatus of this invention provides a heated zone 40 within the nozzle 20 adjacent to or which contains the discharge opening 42. Heating means (not shown in FIG. 2) disposed externally of the nozzle liner 44 maintain the temperature of the liner 44 within the heated zone 40 sufficiently high to effectively prevent solidification of the molten metal within the heated zone 40. In a preferred form of the invention, the nozzle liner 44 within the heated zone 40 is maintained at a sufficiently high temperature so that insufficient heat is extracted from the molten metal 26 within the zone 40 to cause solidification within zone 40.

To effect and maintain the condition necessary to insure optimum performance, zone 40 within nozzle liner 44 should be maintained at or near the melting temperature of the metal. This is to prevent solidification of metal in zone 40 which might connect itself with any solidified metal within the mold. The heat transfer across the wall of nozzle 44 within zone 40 may be either negative, neutral or positive, that is, the heat may transfer from the metal stream to the nozzle wall (negative) or no heat may be transferred in either direction (neutral) or heat may go from the nozzle wall to the metal stream. Since a certain amount of superheat is usually provided in the metal supply, a negative heat transfer can be tolerated provided no detrimental solidification takes place. In this fashion, an effective barrier against premature solidification at the crucial zone, i.e. adjacent the nozzle discharge opening, is provided and molten metal flows continuously and uniformly into the mold 22 without impairment of flow. Also, any skin or scale which may have formed within the nozzle 20 on the upstream side of heated zone 40 is prevented from connecting with the initial freezing point 38 of the metal solidifying within the mold 22. It will, therefore, be appreciated that so long as the upstream portion of the nozzle 20 has not had premature solidification occur to the point where the nozzle passageway is clogged, the casting progress will continue in efficient fashion as a direct result of the annular heating zone 40 disposed adjacent discharge opening 42 of nozzle 20. This zone 40 assures the maintenance of the desired continuous supply of molten metal 26 to the mold 22 and thereby facilitates proper functioning of the continuous casting operation.

Referring now TO FIG. 3, there is shown a vertical continuous casting apparatus embodying a specific type of heating means 46 for establishing an annular heating zone 40. To illustrate the function of heating zone 40, the nozzle 20 is illus-

trated as having a molten metal core 26 and a prematurely solidified skin 48 adjacent the nozzle liner 44. The mold 22 provides a point of initial metal solidification 38 closely adjacent the upstream end thereof. The heating means 46 in FIG. 3 is an annular liner 52 supported in an annular refractory collar 54. The heating means 46 is sealingly joined to the mold 22 and the nozzle 20 by means of sealing material 50, which preferably has thermal insulating properties.

Heating of the annular liner 52 is effected through the circulation of hot gases which are heated by means of a gas generator (not shown). The gas is heated at the gas generator and introduced into the heating means 46 through gas inlet channel 56. It is then circulated around baffle plate 58 and exhausted through gas outlet channel 60. Suitable means (not shown) are provided for controlling the temperature and rate of flow of the gases in order to effectively control the temperature of the liner 52 and thereby, accurately control the temperature gradient between the liner 52 and the molten metal 26 within zone 40.

The zone 40 shown in FIG. 3, in addition to having liner 52 contacting the molten metal, has annular transverse heating walls 62, 64 exposed to the molten metal. These transverse walls 62, 64 provide an additional source of heat input for thermal gradient control. If desired, the diameter of zone 40 across liner 52 may be the same as that of the nozzle 20 and mold 22 or may be less than the diameter of nozzle 20 and mold 22 as illustrated.

Considering now the form of horizontal continuous casting apparatus illustrated in FIG. 4, it is seen that the nozzle 8 shown has a generally L-shaped continuous passageway therethrough open at opposite ends. The nozzle 8 has an interior refractory liner 106. The nozzle 8, as illustrated, also has an exteriorly or outwardly disposed thermal insulating material 108 positioned adjacent the liner 106. An outer metal casing 110 is provided. The nozzle 8 has vertical section 102 and horizontal section 104. A pair of mounting members 112 are secured to charging section 102 which is illustrated as being vertical and a corresponding pair of mounting members 114 are secured to discharging section 104 which is illustrated as being horizontal. While these sections 102, 104 have been illustrated as being disposed vertically and horizontally respectively, both may be vertical, curved or of any other desired orientation so long as the thermal effectiveness of the operation of the invention in producing continuous casting is not impaired. Bolts 116 are passed through aligned openings in mounting members 112, 114 and locking nuts 118 retain the bolts 116 in position. The vertical section 102 and horizontal section 104 of nozzle 8 are thereby demountably secured to each other and provide a nozzle 8 having a continuous refractory liner 106 defining passageway 100.

As has been stated above in connection with FIGS. 2 and 3, heated zone 40 adjacent the discharge opening 42 of nozzle 20 provides a thermal barrier to prevent undesired premature solidification of the molten metal 26. While premature solidification within nozzle 20 upstream of the heating zone 40 may be tolerated to the extent to which blockage of the nozzle passage is not effected, it may be desirable, particularly with respect to nozzles of relatively small internal diameter, to reduce or eliminate the premature solidification of the molten metal within the nozzle 20 upstream of the heating zone 40. This may be accomplished by supplying sufficient heat to the nozzle liner 44 upstream of the heated zone in what may be called the charging section 66 of the nozzle 20 (FIGS. 2 and 3). The heating of charging section 66 should be sufficient to so control the thermal gradient across the nozzle charging section 66 that either no heat is withdrawn from the molten metal 26 or that the amount of heat extracted is such that only a tolerable amount of premature solidification occurs and the molten metal flow through the nozzle is maintained.

In the embodiment illustrated in FIG. 4, heating is present in both the vertical section 102 and the horizontal section 104 and is effected through electrical means. An electrical heating coil 130 is provided integrally within vertical section 102. The

coil 130, which may conveniently be an induction coil or a resistance coil, is preferably embedded within thermal insulating material 108 closely adjacent refractory liner 106. Similarly, electrical heating coil 132 is disposed within horizontal section 104 and is preferably positioned within thermal insulating material closely adjacent refractory liner 106. Independent control means (not shown) are provided for coils 130, 132. As the refractory liner will desirably be composed of a material having relatively good thermal transfer properties and the coils 130, 132 are thermally insulated from the metal casing 110 by thermal insulating material 108, effective heat transfer from coils 130, 132 to the interior surface of refractory liner 106 will be obtained.

While for purposes of illustration, integral electrical heating means have been shown, it will be appreciated that heat may be provided by other conventional means, such as fuel heating through a torch (FIG. 8) or furnace gas heated at a remote generator and caused to flow through a heating chamber disposed exteriorly of the nozzle liner for example, in lieu of or in addition to the electrical heating means. If the alternate heat sources are employed in lieu of the heating coils, it may be desirable in some instances to eliminate insulating material 108.

As shown in FIG. 4, the mold 10 is composed of a suitable thermally conductive material such as copper. The mold has an outer mold wall 134 and an inner mold wall 136 which cooperate with transverse mold walls 138 to define a coolant receiving chamber 140. Ports 142, 152 for introducing and withdrawing the liquid coolant, which is generally water, into and out of the mold chamber of jacket 140, are provided. In operation, water is introduced into chamber 140 and absorbs heat which has been extracted from the metal and conducted through inner mold wall 136. The water is then removed from chamber 140 through port 152 and is either disposed on or passed through a heat exchanger or cooling tower in order to cool it prior to reintroducing it into the chamber 140 through port 142.

Mounting brackets 144 secured to horizontal section 104 are aligned with mounting brackets 146 secured to the head or upstream end of mold 10. Bolts 148 are passed through aligned openings in brackets 144, 146 and nuts 150 and threadedly secured to bolts 148. In this fashion, a continuous passageway through the nozzle and mold is established.

In the form of the invention shown in FIG. 4, thermal insulating material 108 terminates in abutting relation with the transverse mold wall 138 disposed at the end of mold 10. Refractory liner 106 has a tapered extension 154 which extends into mold 10 and has an inner surface which diverges radially outwardly as it extends into mold 10. This extension 154, which preferably has a radially outwardly curved surface provides a smooth transition between the relatively small mean internal diameter of horizontal section 104 and the larger mean internal diameter of mold 10. This promotes smooth metal flow and reduces the opportunity for undesired metal collection and buildup in this critical section.

Referring now to FIG. 5, it is seen that a sealing material 156 is continuously provided intermediate the tapered extension 154 and the inner mold wall 136 in order to effectively prevent the entry of molten metal into this area. Were molten metal to enter this area, which is adjacent cooling chamber 140, premature solidification or freezing of the metal would occur at this point. Eventually, a buildup of solidified metal would occur and result in either a disruption of the continuous casting process or the production of an inferior product. Where desired, sealing material 156 may be provided with an additional sealing flange 160 intermediate insulating material 108 and transverse wall 138, as shown in FIG. 5.

Sealing material 156 should possess thermal stability and resist attack by molten metal. It also should exhibit nonwetting properties with respect to the metals with which it will be employed. Finally, it preferably has thermal insulating properties which serve to limit heat extraction across the sealing material through the mold cooling chamber 140. As the avoidance of

metal freezing in the region where the nozzle 8 is joined to the mold is of substantial importance, the sealing material 156 may, therefore serve a dual purpose.

Before proceeding to describe the operation of the apparatus, attention is directed to FIG. 5, which illustrates an alternate method of securing mold 10 to nozzle 8. Brackets 170 which are secured to outer mold wall 134, have passageways through which bolts 172 pass. The bolts 172 pass through or outside of nozzle 8 externally of passageway 100 and are secured at the opposed end by nuts 174, with thermal insulating members 176 provided intermediate metal casing 110 and nuts 174. If desired, the bolts 172 may be water-cooled.

Turning now to the operation of the apparatus and referring once again to FIG. 4, molten metal 6 passes through nozzle 8 into mold 10 and is solidified by the extraction of heat to form hot billet or slab 178. Billet 178 is further cooled after emerging from mold 10 in order to establish cooled billet 180.

In casting with the apparatus of FIG. 4, molten metal 6 may be introduced into vertical section 102 of nozzle 8 by a convenient noncontacting means such as a ladle 2 or, if desired, a tundish may be employed. The vertical section 102 is sufficiently high to accommodate the desired molten metal head H and sufficient molten metal 6 is introduced to establish and maintain this head H. This head H assists in maintaining the rate of flow, at atmospheric pressure, without the need to employ a pressurized vessel. It also provides metal for makeup flow downstream in order to compensate for the natural shrinkage which occurs on cooling of the molten metal and thereby reduces the likelihood of production of billets with shrinkage cavities.

The primary function of electrical heating coils 130 in vertical section 102 is to provide sufficient heat to liner 106 to keep the molten metal 6 flowing through nozzle 8. The temperature may be sufficiently low to permit some formation of skin, provided flow is maintained in the vertical section 102. As will be described below in detail, any skin formed in this section will be prevented from gaining entry into mold 10.

As has been indicated above, one of the main problems in this type of system is to prevent prematurely solidified metal from reaching the discharge end of the nozzle 8. Among the dangers created by such prematurely formed skin or skull is that it will proceed to build up upstream of the mold and create a region where hangup is likely to occur. It also might connect with the solidified metal within the mold and produce a breakout or other billet defect. As is shown in FIGS. 2 and 3, this is prevented in this invention by providing sufficient heat to the nozzle liner at heated zone 40 that the metal will not only be kept flowing, but will always be prevented from solidifying within this zone 40. The temperature gradient may be such that heat flows from the nozzle liner to the metal or that no heat will be transferred between the nozzle liner 44 and the molten metal 26 within zone 40, thereby preventing any extraction of heat from molten metal 26 within zone 40. This will result in preventing passage of skin or other prematurely solidified metal through discharge opening 42. The potential harmful consequences of any solidification which may have occurred in either the ladle 2 or charging section 66 are averted and no solidified metal will be formed within or pass through heater zone 40. Thus, metal within the heated zone 40 will be in a molten state and will pass into cooling mold 10 in that state.

Referring now to FIG. 5, as the tapered liner extension 154 facilitates smooth flow of the material and sealing material 156 prevents the entry of molten metal between extension 154 and inner mold wall 136, metal hangup through restrictions established by prematurely frozen metal are effectively prevented both at the discharge end of the nozzle 8 and at the entry and/or head end of the mold 10. Also, as the mean cross-sectional area of mold 10 is preferably greater than the mean cross-sectional area of nozzle 8, there is a radially outwardly extension of the metal flow as it leaves the nozzle 8. There is, therefore, no constriction in the passageway to induce buildup of frozen metal in this section, as would be the case were the mold of smaller diameter than the nozzle.

As can be seen in FIG. 4, heat is extracted from molten metal 6 within mold 10 through inner mold wall 136. The first portion of the metal to solidify is the portion 182 contacting inner mold wall 136. As heat continues to be extracted, the metal continues to solidify transversely, radially inwardly until the center portion solidifies to establish a completely solidified section. Completion of the solidification process will take place after the billet emerges from mold 10.

As the molten metal 6 emerging from nozzle 8 has been freed of any solid particles or skin, the freezing or solidification of metal at liner extension 154 and at the immediately adjacent cooled inner mold wall 136 are effectively prevented. Initial freezing point 182 is, therefore, disposed downstream of and spaced from both nozzle 8 and the leading or head end of mold 10. No prematurely frozen metal is permitted to pass through the heated zone 40 and connect with initial freezing point 182 within the mold 10. If it is desired to move the initial freezing point 182 further downstream in the mold 10, this may be readily accomplished by either superheating the metal in the furnace to a higher temperature before tapping or adjusting the controls (not shown) for coil 132 or substituting a liner refractory material of higher conductivity as will be described below in order to prevent extraction of heat in the horizontal section or both. This results in increased extraction of heat being required for initial freezing within mold 10 and therefore, this occurs at a position further downstream.

A modified form of nozzle 188 is illustrated in FIG. 6. In this form of nozzle 188, insulating material 108 and refractory liner 106 both terminate in abutting relation with transverse mold wall 138. Appropriate sealing material 156 is between transverse mold wall 138, liner 106 and insulating material 108 in order to prevent entry of molten metal between these members.

It will be appreciated that throughout the nozzle liner 106 the refractory material must be capable of withstanding the highest temperatures to which it will be exposed. As is shown in the embodiment illustrated in FIG. 6, the discharge end of nozzle 188 may have a refractory material 186 of higher thermal conductivity and higher refractoriness than the material of the remainder of the refractory nozzle liner 106. Any suitable material having these properties, such as graphite or zirconia, for example, may be employed. This material of increased thermal conductivity produces maximum heating of the nozzle liner 106 within zone 40 to maintain the molten metal at an elevated temperature immediately prior to entry into mold 10 and would tend to move initial freezing point 182 (FIG. 4) downstream in mold 10 were the nozzle configuration that of FIG. 4. It is seen, however, that the nozzle 188 has a substantially flared discharge end and that the internal cross-sectional area at the end where refractory 186 is positioned requires more energy to prevent the extraction of heat within this section of nozzle 188. As R2 is greater than R1, more energy must be applied at R2 and the use of highly conductive refractory 186 enhances the transfer of this additional energy.

The nozzle 216 illustrated in FIG. 8 represents a preferred form of the apparatus of this invention. The nozzle liner 218 is composed in part of refractory portion 222 and in part of refractory portion 224. Refractory portion 224 has a higher conductivity than portion 222. This portion 224 is adapted to provide increased heat to the discharge end of nozzle 216. This establishes a temperature gradient between the nozzle interior passage 226 and the exterior of refractory portion 224 such that no detrimental solidification of the metal will occur within this sector and the metal will be introduced into the mold 228 in a molten state.

The heat for this nozzle is provided by means of flame burners disposed externally of the nozzle liner 218 and supplied with fuel through ports 220 from fuel supply means (not shown). This type of heating which is preferred for many types of systems may be employed in lieu of other types of heating means or in addition thereto. In this instance, the flames may be contained within a jacketed heating chamber 230 and are being provided with fuel by means of supply lines (not shown) connected to ports 220. Any convenient fuel such as gas, for example, may be employed.

The nozzle 216 of FIG. 8 has a flanged discharge end 240. In the form illustrated, the flanged end 240 extends into the mold 228 opening, but it may, if desired, terminate in abutting relationship with respect to the mold 228. As will be discussed below, the mean cross-sectional area of the mold 228 is larger than the mean cross-sectional area of the nozzle 216, flanged end 240 provides a transverse heating surface 242. The heat introduced through this surface 242 serves to so control the temperature gradient at the entry portion of the mold 228 and to prevent solidification of the metal and maintain flow of molten metal across surface 242. As the material of flange 240 is preferably of higher conductivity than the remainder of liner 218, the heating along surface 242 is at an increased level with respect to refractory portion 222. A sealing material 244 which preferably has insulating properties, separates inner mold wall 234 and flange 240. This material 244 not only prevents entry of the molten metal between wall 234 and flange 240 but also serves to prevent excessive heat transfer from the flange 240 to the mold 228.

As is shown in FIG. 9, horizontal continuous casting apparatus has a nozzle 68 sealingly joined to a water cooled mold 70. The nozzle 68 has a liner insert 74 of higher thermal conductivity than the rest of the liner 76. The external diameter of the mold 70 is greater than the internal diameter of the nozzle 68. Liner portion 74, therefore, has longitudinal surface 78 and transverse wall or surface 80 in contact with molten metal 26. Thus, the transverse wall 80 permits heating to the full diameter of the billet or slab. Heating of the heated zone 40 and the liner 76 is effected through a plurality of flame fuel burners 80a which are inserted into heating chambers 84. Sealing material 82 which preferably possesses thermal insulating properties is disposed intermediate the upstream end of mold 70 and abutting transverse walls 80. In addition to increased thermal control provided by the transverse wall 80, this embodiment provides added flexibility. As the nozzle 68 abuts the mold 70, rather than extending into the mold 70, the same nozzle 68 may be employed with mold 70 having different diameters. The mold 70 illustrates a large size mold which is in contact with the transverse wall 80 of the nozzle 68. The dotted representation of mold 72 shows a smaller mold adapted for use with the same nozzle 68. Thus by adopting an abutting form of nozzle 68, the thermal advantages of the use of a transverse heated wall 80 are obtained while facilitating flexibility of use of the nozzle equipment.

The apparatus of this invention, therefore prevents any troubles caused by buildup of prematurely solidified metal within the nozzle or within the entry or head portion of mold. As there will be no such hangup within these areas, the only additional potential area of restriction to normal metal movement would be between the inner mold wall 136 and the solidified outer surface 200 of the metal solidified within the desired sections of the mold 10 (FIG. 4). In order to prevent this, the apparatus of this invention provides integral means within the mold 10 to establish a continuous supply of lubricant intermediate the cast billet periphery 200 and inner mold wall 136. As is illustrated in FIG. 7, a lubricant reservoir 202 is defined by inner mold wall 136, outer mold wall 134 and transverse mold walls 138. Suitable pipe 212 for introducing lubricant into reservoir 202 is provided. The reservoir 202 communicates with the mold passageway 158 through a multiplicity of openings 204 in inner mold wall 136. Suitable means such as a pump 206 is provided in order to establish sufficient pressure to create the flow of a lubricant into mold passageway 158. The pump 206 provides lubricant to reservoir 202 through pipe 212. Lubricant is withdrawn from reservoir 202 through pipe 214 which carries it to heat exchanger 208 (the purpose of which will be discussed below). Pipe 210 connects heat exchanger 208 and pump 206.

By selecting a specific size and number of openings 204 and coordinating this with the desired pressure established by pump 206, the amount of lubricant introduced into mold 10, may be effectively controlled. The size of the openings 204 should be such that lubricant will freely flow through them, but should molten metal contact them, the surface tension of

the metal would prevent its entering the openings 204. The openings may be positioned downstream of the point of initial solidification 182.

If desired, the lubricant reservoir 202 may be provided with more than one series of openings 204. Also, if desired, several lubricant reservoirs may be placed in a single mold with water chambers 140 disposed intermediate each pair of lubricant chambers.

When the lubricant chambers 202 of this invention are employed, the lubricant may also advantageously be employed as a coolant. This is accomplished by continuously or intermittently circulating the lubricant through heat exchanger 208 and then after cooling, returning the lubricant to reservoir 202. The lubricant is, therefore, circulated and cooled in a fashion similar to handling of the mold cooling water. Suitable makeup lubricant must, of course be periodically provided. This may be accomplished by conventional means (not shown). The heat exchanger 208 also may be employed in order to maintain the lubricant within a desired temperature range with respect to lubricant properties.

The material employed as a lubricant may be any conventional lubricant such as an oil, grease or graphite, for example. Material such as rape oil, castor oil and mineral oil are also suitable.

For clarity of illustration, the method contemplated by this invention will be discussed in connection with the apparatus illustrated in FIG. 8. It will be appreciated, however, that the method may also be employed with the other forms of apparatus shown in this application. The method of this invention contemplates providing a nozzle 216 having a charging section 217 and a discharging section 219. The nozzle 216 has a refractory nozzle liner 218. The discharging section 219 is provided with heating means 220 disposed externally and closely adjacent the liner 218. A liquid cooled casting mold 228 has its head sealingly joined to the discharging section 219 of the nozzle 216. Molten metal 221 is introduced into the charging section 217 from above and is caused to flow through the nozzle 216 and into the mold 228 where solidification is effected and ultimately the solidified billet or slab 178 emerges from the mold 228. The heating means 220 are adapted to maintain a heated zone within the nozzle liner 218 adjacent the discharge opening 223. The heated zone is maintained at a sufficiently high temperature to prevent solidification of the molten metal within the zone.

This is accomplished by controlling the temperature gradient between the nozzle liner 218 and the molten metal 221. The liner temperature within the heated zone is preferably such that either there is no heat exchange between the nozzle liner 218 and the molten metal 221 or heat is transferred from the nozzle liner 218 to the molten metal 221. The liner temperature within the heated zone is preferably at or above the melting temperature of the metal. The maintenance of a proper temperature gradient between the nozzle liner 224 and the molten metal 221 serves to insure that all metal flowing into the mold 228 will be in the molten state. In addition, if desired, the nozzle liner 222 within the charging section 217 may be continuously heated in order to maintain flow of the molten metal through the charging section 217. As has been indicated above, some solidification within the charging section 217 may be tolerated, as only molten metal will pass through the heated zone.

Referring now to FIG. 4, it is seen that this method effectively prevents connection between any prematurely formed skin and the metal at the initial solidification point 182 within the mold 10. This method also contemplates heating by means of coil 132 so as to controllably position the initial solidification point of the metal within mold 10 at a fixed longitudinal distance downstream of the head end of the mold 10. In a preferred form, after passing into the mold 10, the periphery of the metal is lubricated.

While for purposes of illustration, both vertical continuous casting and horizontal continuous casting systems have been shown, this invention also contemplates curved nozzle and

mold systems and other apparatus orientations, so long as the thermal control stages of the method of the invention are not detrimentally affected.

If, at the end of a casting cycle, it is contemplated that casting will be recommenced within a short time, the heating means may be employed to maintain the nozzle liner at such a temperature that the metal is maintained molten or at an elevated holding temperature until the next casting cycle begins. At that time the output of the heating means is increased to provide sufficient heat to the nozzle liner that the temperature of the metal emerging from the horizontal section 104 will be not less than the melting temperature of the metal.

This system may also be advantageously employed in pouring the initial heat into an empty mold. One or both sections of nozzle 8 may be preheated to the desired temperature prior to the initiating pouring of the molten metal and thereby prevent initial premature freezing of the metal.

Where the next heat will not be poured for an extended period of time, the metal may be allowed to solidify in the nozzle and mold and may be reheated prior to resumption of casting by the heating means. In order to avoid internal defects in the billet created by shrinkage upon cooling in the horizontal casting system, the horizontal section 104 should be cooled first and then the vertical section 102 may be cooled in order to feed the shrinkage cavity in the upper end of the billets.

As this invention facilitates the use of either a noncontacting reservoir 2, such as a ladle or, if desired, a tundish, as a molten metal supply means and the molten metal surface is within the nozzle 8 and separated from the chilling mold, the likelihood of entrapment of nonmetallics from the surface of the molten metal pool is substantially reduced. The avoidance of such entrapment is essential to efficient operation of the continuous casting operation as these nonmetallics are essentially refractory and would inhibit heat extraction from the molten metal. Should such nonmetallics enter the mold, they are likely to result in surface defects along with undesired "breakouts." Because of the surface tension and continued downward flow of the metal during the casting process, the nonmetallic refractory materials are pulled downwardly along the exterior surface adjacent the mold liner. The distance between the free upper surface of the molten metal and the solidified section of the billet greatly reduces the likelihood of such an occurrence. Also, ready access to the top of the molten pool in vertical section 102 is provided and a skimmer may be employed to remove such foreign material, if desired. The herein described arrangement of a heated zone between the mold and the upper surface of the molten metal eliminates the problems now present in vertical casting processes caused by the entrapment of nonmetallics in the cast billet.

It will be appreciated, therefore, that this invention provides apparatus and a method for effectively eliminating hangup within a continuous casting mold by providing a thermal barrier zone which prevents solidification of sealed connection between a nozzle of specific configuration and material and a mold of enlarged internal cross-sectional area with respect to the nozzle is provided. All metal transferred from the nozzle to the mold is completely molten and solidification will be initiated within the mold at a point controllably disposed at a position longitudinally removed downstream from the head end of the mold. As the metal provided to the mold is molten and buildup of undesirable skin is eliminated, the need for supplemental means for effecting metal movement such as mechanical reciprocation, pressurized vessels and lubrication are substantially reduced or eliminated. In addition, the heating means may be insulated against heat losses to the exterior or the metal shell, thereby increasing the thermal efficiency and heat output of the heating means.

While it is not essential to the proper functioning of this invention, one form of the invention facilitates the advantageous use of a lubricant. The lubricant, which may also serve as a cooling fluid, is stored within a reservoir in the mold walls and is provided intermediate the metal periphery and the inner mold wall 136. In another preferred embodiment, (FIG. 6)

one or more sections of the nozzle 188 may be lined with refractory material of different thermal conductivities. Also, the use of noncontacting molten metal supply vessels is facilitated and a tundish need not be employed. The removal of nonmetallics from the molten metal pool surface is therefore facilitated. Where delays or shutdowns are encountered, one or both of the integral heating means may be employed to heat the nozzle and cause it to function as a holding furnace.

As a result of the uniform continuous heating and remelting, smooth movement of metal through both nozzle and mold are established. This coupled with the carefully controlled position of the initiation of solidification to produce the billet, results in a cast billet having uniform high quality.

While for purposes of illustration, several types of heating means have been illustrated, it will be appreciated that various combinations of these as well as other types of heating means may be employed with the apparatus and methods of this invention.

While for purposes of illustration, individual mold and nozzle units have been shown, it will be appreciated that it is contemplated that two or more such nozzle units may be employed as modular units to establish an enlarged supply of molten metal for casting of a larger billet or slab to the combined supplies of multiplicity of such units.

Whereas, particular embodiments of the invention have been described above for purposes of illustration, it will be apparent to those skilled in the art that numerous variations of the details may be made without departing from the appended claims.

I claim:

1. In apparatus for continuous casting of metal, a nozzle having a continuous passageway therethrough open at opposite ends,

said nozzle having a charging section with an opening for receipt of molten metal and a discharging section with an opening for the discharge of molten metal,

a cooled mold sealingly joined to and communicating with said discharge opening of said discharging section and adapted to receive molten metal therefrom.

said continuous passageway within said discharge section of said nozzle having a smaller diameter than said cooled mold,

said nozzle liner terminating at said discharge opening in a transverse heating wall beyond which molten metal is conveyed into said mold,

heating means providing an annular heated zone within said nozzle and said discharge opening for preventing solidification of said molten metal at said discharge opening,

said heating means having a heat source adapted to maintain the liner of said nozzle within said heated zone at a sufficiently high temperature to prevent solidification of said metal.

2. The apparatus of claim 1 wherein, said transverse heating wall terminates in abutting relationship with respect to the upstream end of said mold.

3. The apparatus of claim 1 wherein, a portion of said discharge section of said nozzle extends into said mold, and said transverse heating wall is disposed within said mold.

4. The apparatus of claim 1 wherein, auxiliary heating means are provided to heat said nozzle liner within said charging section to a temperature sufficient to maintain flow of said molten metal through said charging section.

5. The apparatus of claim 1 wherein, said charging section is vertically disposed, said discharging section and said cooled mold are horizontally disposed,

said nozzle has a liner of refractory material and insulating material disposed externally of and adjacent to said liner, said heating means for said discharging section has an electrical heating coil disposed within said insulating material of said horizontal section closely adjacent said inner liner,

said auxiliary heating means has an electrical heating coil disposed within said insulating material of said vertical section closely adjacent said inner liner, and a metal casing disposed externally of said insulating material.

6. The apparatus of claim 1 wherein,
 a tapered extension of said refractory liner of said nozzle extends into said mold,
 the inner surface of said tapered refractory liner extension diverges radially outwardly as it extends into said mold,
 said inner surface has a substantially smooth annular curved surface terminating adjacent the interior wall of said mold, and
 sealing means possessing thermal insulating properties intermediate said extension of said refractory liner and said mold.
7. The apparatus of claim 1 wherein,
 said mold has an interior mold wall, an exterior mold wall and transverse mold walls defining a plurality of liquid receiving chambers,
 at least one said liquid receiving chamber adapted to receive liquid coolant,
 at least one said liquid receiving chamber adapted to receive liquid lubricant,
 said lubricant receiving chamber communicating with the mold interior through a multiplicity of openings in said interior mold wall disposed in spaced relationship with respect to the head of said mold, and
 said opening in said interior wall being sufficiently large to permit passage of lubricant from said lubricant receiving

chambers into said mold interior, but sufficiently small to prevent passage of molten metal into said openings.

8. The apparatus of claim 4 wherein,
 said heating means for said heated zone has a heating chamber disposed exteriorly of and adjacent to said nozzle liner.
9. The apparatus of claim 5 wherein,
 said vertical section of said nozzle is of sufficient height to provide a head of molten metal adequate to establish the fluid pressure required for continuous casting when said vertical section is exposed to a pressure not greater than atmospheric pressure.
10. The apparatus of claim 6 wherein,
 said heating means for said discharging section has a heat source, for heating gas,
 means communicating with said heating source and said heating chamber for transferring said heated gas into said heated chamber, and
 means for withdrawing said heated gas from said heating chamber.
11. The apparatus of claim 6 wherein,
 said heating means for said discharging section has at least one fuel fired burner extending into said heating chamber.
12. The apparatus of claim 1 wherein,
 a substantial portion of said liner of said heated zone adjacent said nozzle discharge opening is composed of a refractory material having a higher thermal conductivity than the remainder of said liner.

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