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(11) **EP 0 982 088 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
01.03.2000 Bulletin 2000/09

(51) Int. Cl.⁷: **B22D 11/10, B22D 41/58,
B22D 41/42**

(21) Application number: **99304054.2**

(22) Date of filing: **25.05.1999**

(84) Designated Contracting States:
**AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU
MC NL PT SE**
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: **31.07.1998 US 126617**

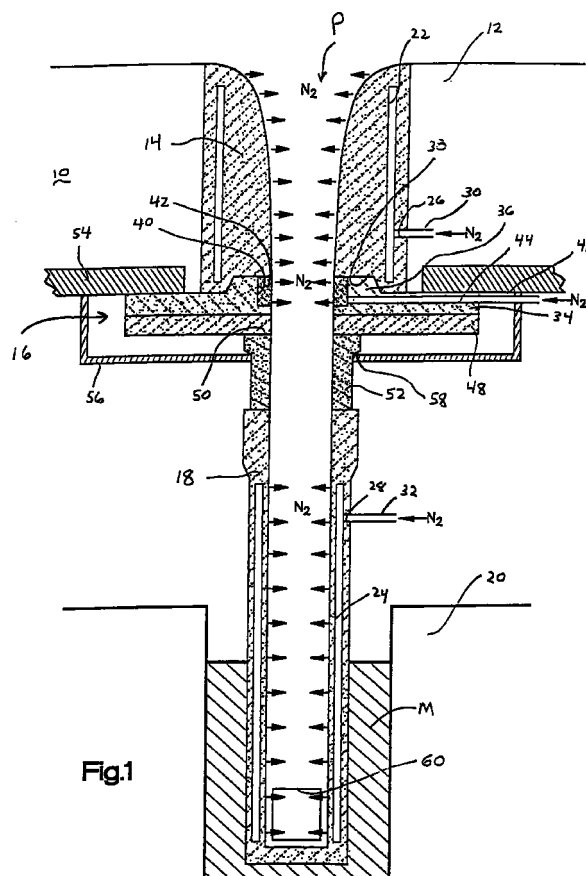
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(54) **Preventing pencil pipe defects in steel**

(57) A method of eliminating pencil pipe defects in steel includes the step of flowing molten steel through a passageway (P) that may be formed by: an upper tundish nozzle (14) disposed beneath a tundish (12); nozzle plates (16) for controlling flow of the molten steel; and an entry nozzle (18) disposed between the nozzle plates and a mold. Nitrogen-containing gas is directed under predetermined gas flow conditions along substantially an entire length of the passageway. The gas may be directed to portions of the passageway formed by the upper tundish nozzle and the nozzle plates and into the passageway. The molten steel may be exposed to the gas directed under the predetermined gas flow conditions to a portion of the passageway formed by the entry nozzle. Instead of or in addition to exposure to the nitrogen-containing gas, the molten steel may be exposed to a reactive surface (94) formed of a CaO-ZrO₂ composition, the reactive surface forming a portion of the entry nozzle. The nitrogen-containing gas may also be directed through a porous refractory sleeve of the entry nozzle and into the passageway. The gas flow conditions are effective to eliminate pencil pipe defects in the steel.



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Description

Field of the Invention:

[0001] The invention is directed to the field of the continuous casting of molten steel.

Background of the Invention:

[0002] Steel is continuously cast by delivering it in molten form from a tundish through the bore of refractory nozzle components and into a continuous casting mold. The typical refractory components are an upper tundish nozzle disposed beneath a tundish, refractory plates to control flow, and a submerged entry nozzle that extends into molten steel in the mold. Aluminum oxide inclusions in the steel tend to deposit on the refractory walls of the components over time. Such buildup will choke off the bore and terminate casting unless prevented. The conventional way to prevent such nozzle clogging is to deliver argon gas to the bore, through a porous refractory material of the upper tundish nozzle and an upper slide plate. The argon gas bubbles exiting the refractory pores are intended to prevent aluminum oxide particles from contacting and adhering to the refractory walls and to prevent nozzle clogging.

[0003] In the case of continuous casting machines having curved portions, some of the injected argon gas bubbles become trapped at the inner radius of solidifying strands of steel. This is a particular problem for ultra low carbon (ULC) or extra low carbon (ELC) steel. During subsequent high temperature annealing of the coiled steel, the trapped argon bubbles may expand and "blister" the surface of coils of the steel, rendering the formed steel unsuitable for exposed automotive applications. This argon-based, raised surface coil defect is known as a "pencil pipe" defect or a "blister." In an attempt to eliminate this defect, one approach has been to cast pencil-pipe sensitive steel at very low cast speeds or steel throughputs. This can be a very significant production disadvantage to steel producers. Pencil pipe defects and clogging of the nozzle components thus continue to be serious problems for steel producers.

Summary of the Invention:

[0004] In general form, the present invention can direct nitrogen-containing gas along substantially an entire passageway formed by a nozzle assembly to avoid pencil pipe defects upon high temperature annealing of resulting coils of the steel. Any portions of the passageway which are not subjected to the nitrogen-containing gas such as the entry nozzle, can include insert sleeves formed of a lime-zirconia material. The passageway extends between a tundish and a mold of a continuous casting apparatus. The invention

is particularly applicable to the use of ultra low carbon and extra low carbon steel, which are susceptible to pencil pipe defects in view of their reduced strength. The invention is also applicable to the use of continuous casters having curved portions, in which the inner strand of steel is susceptible to pencil pipe defects. The present invention avoids the conventional use of argon, which has been the cause of pencil pipe defects. By using the nitrogen-containing gas under predetermined flow conditions that prevent excess nitrogen pick-up in the steel and yet inhibit clogging, the present invention offers a valuable solution to the pencil pipe problem that has been faced by continuous casting steel producers.

[0005] One embodiment of the present invention is directed to a method of eliminating pencil pipe defects in steel, comprising the step of flowing molten steel through a passageway formed by: an upper tundish nozzle disposed beneath a tundish; nozzle plates for controlling flow of the molten steel; and an entry nozzle disposed between the nozzle plates and a mold, in particular, the entry nozzle being submerged in molten steel of the mold. A nitrogen-containing gas is directed under predetermined gas flow conditions to portions of the passageway formed by the upper tundish nozzle, the nozzle plates and the entry nozzle. The gas flow conditions are effective to eliminate pencil pipe defects in the steel.

[0006] In particular, the upper tundish nozzle, the nozzle plates and the submerged entry nozzle comprise a porous refractory material through which the nitrogen-containing gas is passed. The molten steel is passed through the passageway and into the mold which forms a part of a continuous casting apparatus, and especially, into arcuate mold portions of the continuous casting apparatus. The gas flow conditions are effective to prevent excessive nitrogen accumulation in the steel.

[0007] Either a two or a three nozzle plate assembly is preferably employed. The two-plate nozzle assembly includes a stationary upper plate and a lower, movable throttle plate. An intermediate nozzle is disposed between the throttle plate and the entry nozzle. The gas is passed to portions of the passageway formed by the upper plate. The three-plate assembly includes a stationary upper plate, a movable middle throttle plate, and a stationary lower plate. The submerged entry nozzle includes an upper surface that is in contact with the lower plate. The gas is passed to portions of the passageway formed by the upper plate and the lower plate.

[0008] As to preferable processing parameters, the nitrogen-containing gas is directed at flow rates through the upper tundish nozzle, the upper nozzle plate, and the submerged entry nozzle in ranges of from about 8 to about 12 liters/minute (l/min), from about 2 to about 6 l/min and from about 2 to about 6 l/min, respectively. The nitrogen-containing gas is directed at back pressures through the upper tundish nozzle, the upper nozzle plate, and the submerged entry nozzle in ranges of from about 10 to about 15 pounds per square inch (psi),

from about 12 to about 20 psi and from about 1.5 to about 5.0 psi, respectively. If a third lower plate is used in the nozzle plate assembly (*i.e.*, the three-plate assembly), the nitrogen-containing gas is directed through it at a flow rate ranging from about 10 to about 14 l/min at a back pressure ranging from about 3 to about 6 psi.

[0009] Another preferred embodiment of the invention is directed to a method of eliminating pencil pipe defects in steel, comprising the step of flowing molten steel through the passageway formed by: the upper tundish nozzle disposed beneath the tundish; the nozzle plates; and the submerged entry nozzle disposed between the nozzle plates and the mold. The nitrogen-containing gas is directed under predetermined gas flow conditions to portions of the passageway formed by the upper nozzle and the nozzle plates and into the passageway. The molten steel is exposed to the gas which is directed under the predetermined gas flow conditions to a portion of the passageway formed by the submerged entry nozzle. Instead of or in addition to exposing the molten steel adjacent the submerged entry nozzle to the nitrogen-containing gas, the molten steel may be exposed to a "slippery bore" reactive surface formed of a CaO-ZrO₂ composition, the reactive surface forming a portion of the submerged entry nozzle. The nitrogen-containing gas may be directed through a porous refractory sleeve of the submerged entry nozzle (formed of the slippery bore insert material or a different porous refractory) and into the passageway. The gas flow conditions are effective to eliminate pencil pipe defects in the steel.

[0010] The present invention offers numerous advantages over conventional continuous casting production. The inventive method employs nitrogen gas, which is relatively inexpensive. More importantly, the invention eliminates the occurrence of pencil pipe defects. When using the inventive method, steel sheet such as in exposed automotive applications, in particular formed by ELC or ULC steel cast using a continuous caster with curved mold portions, will no longer suffer from pencil pipe defects. Steel sheet made by hot rolling slabs of solidified steel processed according to the present invention, can now be widely used in these and other exposed applications. Therefore, the present method offers a significant cost advantage to steel producers by fully utilizing the steel that is produced, and provides automotive manufacturers with a product of superior quality. All of these advantages are achieved at a molten steel throughput at the continuous caster that is the same as or faster than in conventional practices.

[0011] Many additional features, advantages and a fuller understanding of the invention will be had from the accompanying drawings and the detailed description that follows.

Brief Description of the Drawings:

[0012]

Figure 1 is a vertical cross-sectional view of one embodiment of a nozzle assembly used in the method of the present invention;

Figure 2 is a vertical cross-sectional view of another, more preferred embodiment of a nozzle assembly used in the method of the present invention; and

Figure 3 is a vertical cross-sectional view of an entry nozzle employing a refractory portion, which may be used in the method of the present invention.

Detailed Description of Preferred Embodiments:

[0013] Referring now to the drawings, Fig. 1 refers to a nozzle assembly used in the method of the present invention designated generally at 10. Molten steel M flows from a distribution vessel or tundish 12 through a passageway P formed by an upper tundish nozzle ("UTN") 14, a movable gate plate assembly 16 and a lower or submerged entry nozzle ("SEN") 18, and into a portion of a mold 20 of a continuous caster. A nitrogen-containing gas depicted as "N₂" in the drawings is directed to portions of the passageway formed by each of the UTN 14 and the gate plate assembly 16 under predetermined gas flow conditions. Nitrogen-containing gas can also be directed to the SEN 18, under predetermined gas flow conditions, although injection of the nitrogen-containing gas at the SEN is optional if slippery bore inserts are employed in the SEN.

[0014] Annular spaces or slits 22, 24 are preferably formed in each of the UTN 14 and SEN 18 by known techniques. The sizes of the annular slits are not drawn to scale, but may be enlarged somewhat for clarity of description. A wax ring or paper may be used during manufacturing of the refractory component, in the location of the annular space. Upon firing of the refractory the wax ring or paper burns off, leaving the annular space. The only communication of the annular spaces with the exterior of the components are passageways 26, 28 drilled through the refractory from the exterior surface of the UTN and from the exterior surface of the SEN, to the annular spaces 22, 24, respectively. Gas supply conduits 30, 32 are coupled to these passageways 26, 28, respectively. The nitrogen-containing gas is fed from a gas source through appropriate valves, through the gas supply conduits 30, 32, through the passageways 26, 28, into the annular spaces 22, 24 of the UTN and SEN, and through the refractory into the passageway P. Flowing the gas through the pores of the refractory causes the gas to be released as bubbles into the molten metal.

[0015] The following describes variations that are contemplated by the present invention although not specifically shown in the drawings or described. Other

variations of flowing the gas to the passageway may be possible, such as using a plurality of small transverse passageways through the refractory and to the passageway P (not shown), but are not preferred. Throughout this description it will be apparent that each of the nozzle components has a central bore that forms a portion of the passageway P which extends from the tundish to the mold. In all the drawings molten steel is not shown in the nozzle assembly for improving the clarity of the drawings. Throughout the drawings the gas supply conduits are shown schematically, and it will be appreciated that the gas supply conduits are suitably coupled to the gas passageways in a manner known to those skilled in the art. For example, the gas passageways may be drilled or formed from wax upon firing, and a steel fitting may be fixed with mortar in the passageway. A corresponding fitting of the conduit may be threaded to the fitting in the passageway.

[0016] The slide gate plate assembly 16 may employ two plates as shown in Figure 1. The upper plate 34 of the gate plate assembly includes an upper protrusion 36 that is received by a recess 38 in a lower portion of the UTN for fixing the upper plate in place. The upper plate 34 has a recess 40 that receives a porous sleeve 42 which partially forms the passageway P. In communication with the porous sleeve is a gas passageway 44 that is coupled to a gas supply conduit 46. The lower plate is a throttle plate 48 with an annular opening that forms a portion of the passageway P. The upper plate and the throttle plate each include a centrally located opening for forming a portion of the passageway. The throttle plate 48 slides between the upper plate 34 and a flat upper surface 50 of an intermediate nozzle 52 that is secured to the SEN 18. Movement of the throttle plate blocks or permits the flow of molten metal through the passageway P.

[0017] For supporting the nozzle assembly, a mounting plate 54 is mounted to the tundish shell. Fastened to the mounting plate is a cassette 56. Both the mounting plate and the cassette are formed of metal. The cassette is engaged below a flange 58 formed on the intermediate nozzle, to support the nozzle assembly in place.

[0018] The SEN includes exit ports 60 at its lower end. The annular slit 24 extends in "dog-ear" fashion between the outlet ports of the SEN without communicating with the ports.

[0019] Figure 2 refers to a preferred nozzle assembly used in the method of the present invention designated generally at 80, where like reference numerals designate like parts through the views. Molten steel M flows from a tundish 12 through a passageway P formed by an upper tundish nozzle ("UTN") 14, a movable gate plate assembly 17 and a lower or submerged entry nozzle ("SEN") 18, and into a portion of a mold 20 of a continuous caster. A nitrogen-containing gas, which is depicted as "N₂" in the figure, is directed to portions of the passageway formed by each of the UTN 14 and the

gate plate assembly 17 under predetermined gas flow conditions. Nitrogen-containing gas is also directed to the SEN 18, under predetermined gas flow conditions, but use of the nitrogen-containing gas at the SEN is optional if slippery bore inserts are employed in the SEN.

[0020] The annular spaces 22, 24 are preferably formed in each of the UTN 14 and SEN 18 by known techniques, for example, using the wax ring/paper manufacturing procedure. The only communication of the annular spaces with the exterior of the components are the passageways 26, 28 drilled through the refractory from the exterior surface of the UTN and from the exterior surface of the SEN to the annular spaces 22, 24, respectively. The gas supply conduits 30, 32 are coupled to these passageways 26, 28, respectively. The gas is fed from a gas source through appropriate valves, through the gas supply conduits 30, 32, and the passageways 26, 28, into the annular spaces 22, 24 of the UTN and SEN, and through the refractory into the passageway P. Flowing the gas through the pores of the refractory causes the gas to be released as bubbles into the molten metal. Other variations of flowing the gas to the passageway may be possible such as using a plurality of small transverse passageways through the refractory and to the passageway P (not shown), but are not preferred.

[0021] The sliding gate assembly 17 is a three-plate system which employs an additional stationary lower plate 82 compared to the gate assembly 16 shown in Fig. 1. This assembly 17 employs the similar porous upper plate 34 as in the two-plate assembly. The assembly 17 also employs a similar throttle plate 48 as in the two-plate assembly. The lower plate 82 includes an annular groove 84 at a lower portion thereof in communication with a flat upper surface of the SEN. A gas passageway 88 is drilled into the refractory into communication with the annular groove. A gas supply conduit 90 is coupled to the gas passageway 88. Each of the upper plate, the throttle plate and the lower plate includes a centrally located opening that partially forms the passageway P. The throttle plate 48 slides between the upper plate 24 and the lower plate 82. Movement of the throttle plate blocks or permits the flow of molten steel in the passageway P.

[0022] During the casting operation using the three-plate gate assembly shown in Fig. 2, graphite powder is entrained, using appropriate valves, into the nitrogen-containing gas stream to the annular groove 84. When nitrogen gas is used instead of argon and when no graphite injection is used, a vacuum is created which aspirates air into the joint between the upper surface 86 of the SEN and the lower surface 92 of the lower plate 82 of the gate assembly. The air enters the passageway and forms alumina in the molten steel, leading to clogging of the passageway. Graphite is injected to prevent clogging due to aspiration. The graphite seals this joint and prevents the air from entering the passageway,

thereby avoiding clogging. This graphite injection process has been developed by Vesuvius Refractories.

[0023] For supporting the nozzle assembly, the mounting plate 54 is mounted to the tundish shell. Fastened to the mounting plate is the cassette 56. The cassette engages the lower surface 92 of the lower gate plate 82 to support the nozzle assembly 80 in place.

[0024] In the preferred embodiment shown in Figure 2, the vertical slit 24 formed in the SEN preferably extends to a greater height than in the SEN shown in Figure 1. All but an upper end portion of the SEN contains the slit. This feature is preferably combined with the use of the three-plate gate assembly to reduce clogging of the passageway P.

[0025] The UTN, the slide gate plate and the SEN of all embodiments are formed of refractory components that are designed to have a sufficiently small pore size to ensure high back pressure. The UTN is formed of porous alumina or magnesium oxide. The upper plate of the two-plate assembly and the upper plate of the three-plate gate assembly, are formed of one of porous alumina, zirconia or magnesia. In the three-plate gate assembly a zirconia insert (not shown) extends at least on the sliding surfaces of the lower plate and the throttle plate. The SEN body is formed of alumina and graphite.

[0026] Nozzle components suitable for use in the present invention may be formed of various compositions, and with individual portions or inserts of each component formed of different compositions, other than what is specifically shown and described herein. For example, the SEN shown in Figure 1 may have a refractory body of one composition and a porous portion located radially inward of the slit forming a portion of the bore, located in a position such as the position of the sleeve shown in Figure 3. The SEN and the intermediate nozzle, depending upon whether a two or three plate gate apparatus is used, may be formed with portions having different compositions than the body, which exhibit properties such as are suitable for the wear encountered by the throttle plate.

[0027] In particular, the UTN was supplied by TYK Refractory Co., Model No. DAS-7. The three-plate gate assembly was supplied by Vesuvius Refractories and employs their upper plate with a porous mix, and throttle and lower plates. The two-plate gate system may be supplied by Kurosaki Co.; this assembly may employ a porous upper plate, and a lower plate and intermediate nozzle, supplied by North American Refractories Co. The SEN was supplied by Shinagawa Refractories Co., Model No. SBX-G32H6 (body mix) and SBX-G1801 (inner bore porous mix).

[0028] Referring to Fig. 3, a slippery bore insert(s) (generally shown at 94) may be used in the main passageway and between the ports of the SEN. The slippery bore inserts are comprised of a lime-zirconia (e.g., CaO-ZrO_2) material. If the slippery bore inserts are used, the SEN preferably does not employ gas injection. When no slippery bore inserts are used as in Figs. 1

and 2, the SEN is slitted and employs gas injection. The slippery bore inserts shown in Figure 3 may be used in the assembly 10 of Fig. 1 and in the assembly 80 of Fig. 2 without gas injection.

[0029] The slippery bore inserts may also be formed to be sufficiently porous so that the nitrogen-containing gas can be passed through them. In this case, a gas passageway 96 is drilled through the SEN into communication with the slippery bore inserts 94. Coupled to the passageway is a gas conduit 98. Other porous refractory inserts may also be employed in place of the slippery bore inserts 94, and are located in a position similar to that of the inserts shown in Figure 3, while employing gas injection.

[0030] The predetermined gas flow conditions are broadly defined herein as flow rates and/or back pressures which are effective to prevent excessive nitrogen pick-up in the steel according to conventional tolerable levels of nitrogen, to inhibit clogging of the nozzle components, and to prevent pencil pipe defects in coils of the resulting steel. Since nitrogen dissolves quickly in the molten steel, low gas flow rates minimize undesirable nitrogen pickup in the steel. Moreover, since the nitrogen dissolves in the steel, there are no bubbles which expand during annealing.

[0031] The nitrogen-containing gas may contain a gas or gases other than nitrogen but is preferably substantially all nitrogen gas, even more preferably, 100% nitrogen gas. To prevent pencil pipe defects and inhibit clogging, the gas is directed to each of the UTN, the slide gate plate assembly and the SEN (unless a slippery bore insert is used in which case the gas injection is optional). Injecting the nitrogen-containing gas to portions of the passageway formed by only one or two of the components, if a slippery bore insert is not used, is not sufficient to inhibit clogging. Argon gas is preferably not utilized in the present invention since even when present in small amounts it may lead to pencil pipe defects.

[0032] While not wanting to be bound by theory, the lime-zirconia slippery bore inserts are believed to prevent the formation and accumulation of alumina on surfaces that form the bore of the SEN. The material of the slippery bore inserts is believed to be reactive. It is believed that the solid alumina which deposits in the SEN bore and ports reacts with the lime content of the inserts to form liquid calcium aluminate inclusions in the molten steel. The calcium aluminate inclusions are believed to flow with the steel into the casting mold and are not injurious to the final steel sheet product. The nitrogen bubbles at the UTN and the gate plate assembly (and nitrogen gas bubbles at the SEN when gas injection is used at the SEN) are believed to provide a scrubbing action on the surfaces of the bore to prevent deposition and accumulation of alumina. Some of the nitrogen bubbles may help to liberate the liquid calcium aluminate from the SEN and expose new lime units to react with the solid alumina particles.

[0033] In the case of using the slitted SEN without a slippery bore, the flow rates of nitrogen gas at the upper tundish nozzle, the upper slide gate plate and the submerged entry nozzle are, for example, in the range of: from about 8 to about 12 liters/minute (l/min), from about 2 to about 6 l/min and from about 2 to about 6 l/min, respectively. Back pressures to the tundish nozzle, the upper gate plate and the SEN are, for example, in the range of: from about 10 to about 15 psi, from about 12 to about 20 psi and from about 1.5 to about 5.0 psi, respectively. Graphite injection at the lower plate is preferably used to prevent clogging due to aspiration. At the lower plate groove of the gate assembly, the nitrogen-containing gas flows at a rate in the range of, for example, from about 10 to about 14 l/min, with about 10 l/min being preferred. The back pressure to the annular opening at the lower plate is, for example, in the range of from about 3 to about 6 psi, with about 4 psi being preferred. Back pressure is measured continuously at the passageway while nitrogen injection occurs. The continuous caster is operated at throughputs up to about 4.5 tons of molten steel per minute. It is believed that under the foregoing conditions the resulting coils of steel will not exhibit any noticeable pencil pipe defects after annealing.

[0034] In the case of using a non-slitted SEN employing the slippery bore inserts, the flow rates of nitrogen gas at the upper tundish nozzle and the upper slide gate plate are, for example, in the range of: from about 8 to about 12 l/min and from about 2 to about 8 l/min, respectively. Back pressures to the tundish nozzle and the upper gate plate are: about 10 to about 15 psi and about 12 to about 20 psi, respectively. Graphite injection at the lower plate is used to prevent clogging due to aspiration. At the lower plate of the gate assembly, the nitrogen-containing gas flows at a rate in the range of, for example, from about 10 to about 14 l/min, with about 10 l/min being preferred. The back pressure to the annular opening at the lower plate is, for example, in the range of from about 3 to about 6 psi, with about 4 psi being preferred. It is believed that under the foregoing conditions the resulting coils of steel will not exhibit any noticeable pencil pipe defects after annealing.

[0035] In the method of the present invention, since nitrogen rather than argon gas is used, instances of clogging of the SEN may increase due to the rapid dissolving of nitrogen into the steel and thus the lesser effectiveness of nitrogen in reducing clogging. Therefore, the SEN's may be changed more frequently. The SEN's are preferably changed using a commercially available SEN carriage replacement system.

[0036] Preferred aspects of the invention will now be described by reference to the following non-limiting examples.

EXAMPLE 1

[0037] The slitted SEN was used without slippery bore

inserts in a curved continuous caster casting ELC or ULC steel. The flow rates of nitrogen gas at the UTN, the upper slide gate plate, the lower slide gate plate and the SEN were: about 10 l/min, about 4 l/min, about 10 l/min and about 4 l/min, respectively. Back pressures to the UTN, the upper slide gate plate, the lower slide gate plate and the SEN were: about 12 psi, about 16 psi, about 4 psi and under 5 psi, respectively. The SEN had a lifetime of about 120-250 minutes (275-650 tons), due to alumina clogging of the SEN. Graphite injection at the lower plate was used to prevent clogging due to aspiration. The continuous caster was operated at throughputs up to about 4.5 tons of molten steel per minute. The resulting coiled steel did not exhibit any noticeable pencil pipe defects after annealing.

EXAMPLE 2

[0038] A SEN supplied by TYK Refractories Co., was used without gas injection, employing CaO-ZrO₂ slippery bore inserts in the bore and around the ports designated by the trade name PA5C in a curved continuous caster casting ELC or ULC steel. The flow rates of nitrogen gas at the tundish nozzle, the upper slide gate plate and the lower slide gate plate were: about 10 l/min, about 5 l/min and about 10 l/min, respectively. Back pressures to the tundish nozzle, the upper gate plate and the lower gate plate were: about 12 psi, about 16 psi and about 4 psi, respectively. Graphite injection at the lower plate was used to prevent clogging due to aspiration. The SEN had a lifetime of about 120-250 minutes (275-650 tons), due to alumina clogging of the SEN. The continuous caster was operated at throughputs up to about 4.5 tons of molten steel per minute. The resulting coiled steel did not exhibit any noticeable pencil pipe defects after annealing.

COMPARATIVE EXAMPLE

[0039] A regular SEN was used without gas injection and without slippery bore inserts in a curved continuous caster casting ELC or ULC steel. The flow rate of nitrogen gas at the UTN was 12 l/min and the flow rate of argon at the upper gate plate was 6-8 l/min. Back pressures to the UTN and the upper gate plate were: 12 psi and 16 psi, respectively. The SEN had a lifetime of about 200-350 minutes. The continuous caster was operated at throughputs of under 3 tons of molten steel per minute. Although the SEN's used in this process had a greater life due to less clogging, coils of the resulting steel sheet exhibited pencil pipe defects after annealing, which significantly reduced the value of the steel.

[0040] Many modifications and variations of the invention will be apparent to those of ordinary skill in the art in light of the foregoing disclosure. Therefore, it is to be understood that, within the scope of the appended claims, the invention can be practiced otherwise than

has been specifically shown and described.

Claims

1. A method of eliminating pencil pipe defects in steel, comprising the steps of
 - flowing molten steel through a passageway formed by: an upper tundish nozzle disposed beneath a tundish; nozzle plates for controlling flow of the molten metal; and an entry nozzle disposed between said nozzle plates and a mold, and
 - directing nitrogen-containing gas under predetermined gas flow conditions to portions of said passageway formed by said upper tundish nozzle, said nozzle plates and said entry nozzle, wherein said gas flow conditions are effective to eliminate pencil pipe defects in said steel.
2. The method of claim 1 comprising passing said molten steel into said mold which forms a part of a continuous casting apparatus.
3. The method of claim 2 comprising passing said molten steel into arcuate mold portions of said continuous casting apparatus.
4. The method of claim 1 wherein said gas flow conditions are effective to prevent excessive nitrogen accumulation in said steel.
5. The method of claim 1 wherein said nozzle plates include a stationary upper plate and a lower throttle plate, further comprising an intermediate nozzle disposed between said throttle plate and said entry nozzle, said throttle plate being movable on an upper surface of said intermediate nozzle, comprising passing the nitrogen-containing gas to portions of said passageway formed by said upper plate.
6. The method of claim 1 wherein said nozzle plates include a stationary upper plate, a movable middle throttle plate, and a stationary lower plate, said entry nozzle being in contact with said lower plate, comprising passing the nitrogen-containing gas to portions of said passageway formed by said upper plate and said lower plate.
7. The method of claim 1 comprising flowing the nitrogen-containing gas at flow rates through the upper tundish nozzle, an upper plate of the nozzle plates, and the entry nozzle in ranges of from about 8 to about 12 l/min, from about 2 to about 6 l/min and from about 2 to about 6 l/min, respectively.
8. The method of claim 1 comprising flowing the nitrogen-containing gas at back pressures through the

upper tundish nozzle, an upper plate of the nozzle plates, and the entry nozzle in ranges from about 10 to about 15 psi, from about 12 to about 20 psi and from about 1.5 to about 5.0 psi, respectively.

9. The method of claim 1 comprising flowing the nitrogen-containing gas at a flow rate through a lower plate of the nozzle plates in a range of from about 10 to about 14 l/min and at a back pressure ranging from about 3 to about 6 psi.
 10. A method of eliminating pencil pipe defects in steel, comprising the steps of
 - flowing molten steel through a passageway formed by: an upper tundish nozzle disposed beneath a tundish; nozzle plates for controlling flow of the molten steel; and an entry nozzle disposed between said nozzle plates and a mold, wherein said upper tundish nozzle, said nozzle plates and said entry nozzle comprise a porous refractory material, and
 - directing nitrogen-containing gas under predetermined gas flow conditions through the porous refractory of said upper nozzle, said nozzle plates, and said entry nozzle, and into said passageway, wherein said gas flow conditions are effective to eliminate pencil pipe defects in said steel.
 11. A method of eliminating pencil pipe defects in steel, comprising the steps of
 - flowing molten steel through a passageway formed by: an upper tundish nozzle disposed beneath a tundish; nozzle plates for controlling flow of the molten steel; and an entry nozzle disposed between said nozzle plates and a mold,
 - directing nitrogen-containing gas under predetermined gas flow conditions to portions of said passageway formed by said upper nozzle and said nozzle plates, and into said passageway, and
 - exposing the molten steel to at least one of the conditions selected from the group consisting of:
 - (a) nitrogen-containing gas which is directed under said predetermined gas flow conditions to a portion of said passageway formed by said entry nozzle, and
 - (b) a reactive surface formed of a CaO-ZrO₂ composition, said reactive surface forming a portion of said entry nozzle,
- wherein said gas flow conditions are effective to eliminate pencil pipe defects in said steel.

12. The method of claim 11 wherein said nitrogen-containing gas is directed under said predetermined gas flow conditions through a porous refractory sleeve of said entry nozzle and into said passageway. 5
13. A method of eliminating pencil pipe defects in steel, comprising the steps of
- flowing molten steel through a passageway 10
formed by a nozzle assembly, said passageway extending between a tundish and a mold, and
directing nitrogen-containing gas under predetermined gas flow conditions along substantially an entire length of the passageway, 15
wherein said gas flow conditions are effective to eliminate pencil pipe defects in said steel.
14. The method of claim 13 wherein components of said nozzle assembly comprise a porous refractory material, comprising passing said nitrogen-containing gas through said refractory material, and into said passageway. 20
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15. A method of casting steel, wherein nitrogen containing gas is introduced into the molten steel during casting, whereby the occurrence of pencil-pipe defects can be reduced. 30
16. Apparatus for casting steel, comprising means for introducing nitrogen-containing gas into the molten steel during casting, whereby the occurrence of pencil-pipe defects can be reduced. 35

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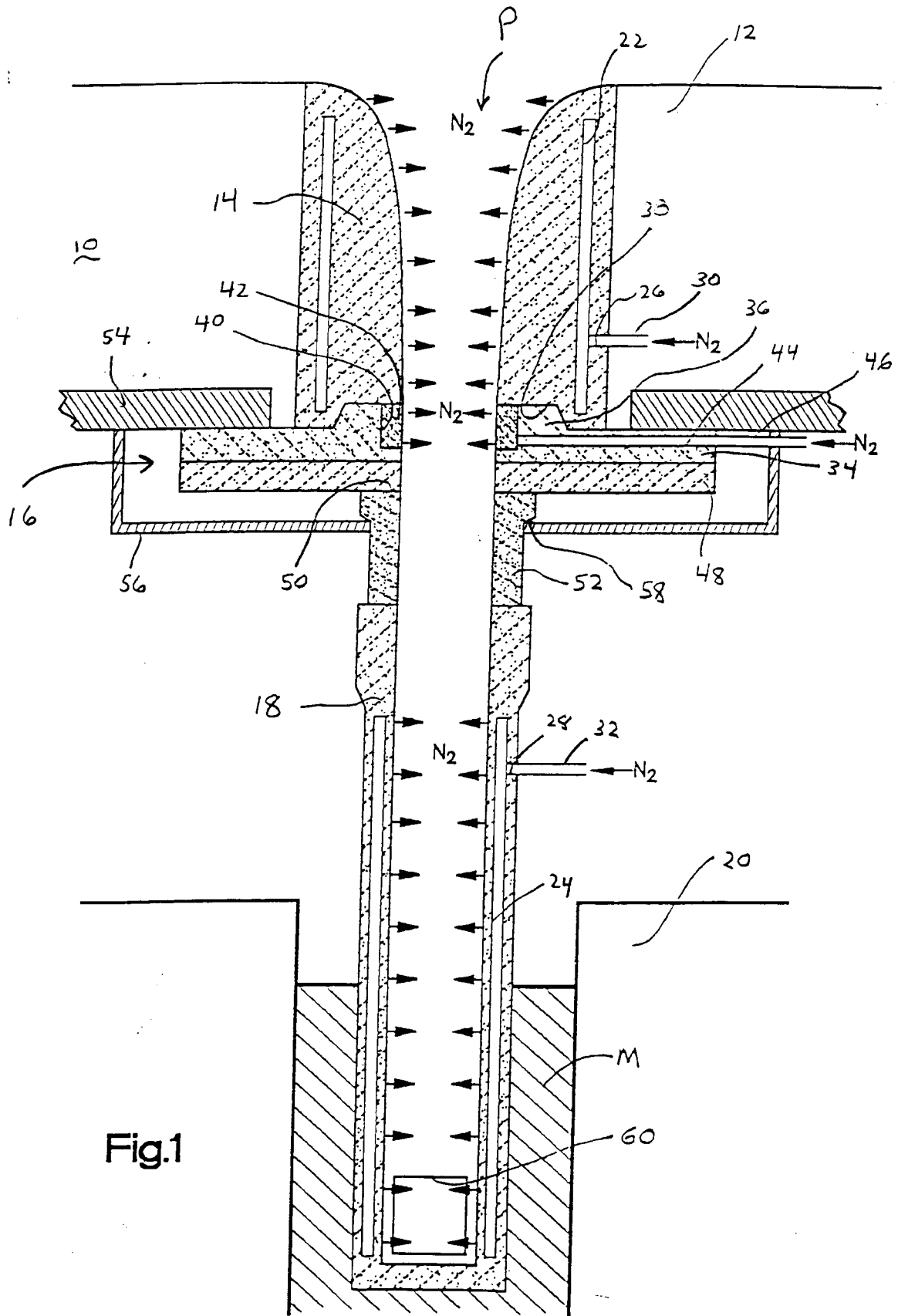


Fig.1

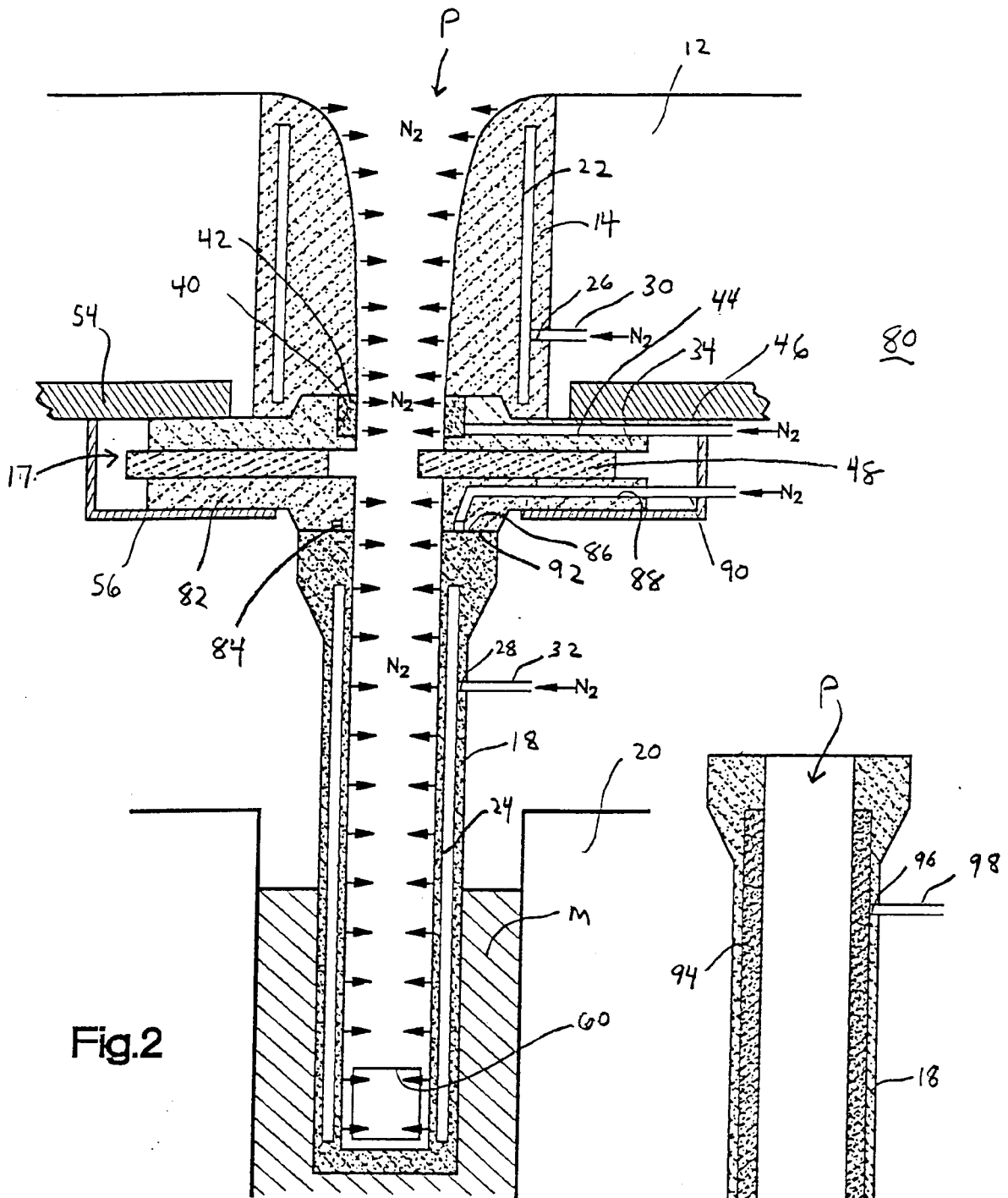


Fig.2

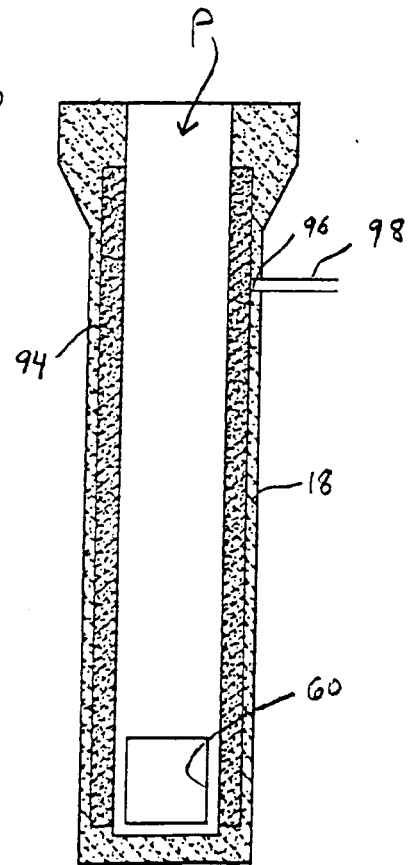


Fig.3



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