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(54) SUBMERGED ENTRY NOZZLE WITH DYNAMIC STABILIZATION

(76) Inventors: **Dong Xu**, Ontario (CA); **Lawrence Heaslip**, Ontario (CA); **Johan Richaud**, Ontario (CA); **James Dorricott**, Ontario (CA)

Correspondence Address:
**Robert S Klemz Jr**
**Vesuvius USA**
**27 Noblestown Road**
**Carnegie, PA 15106-1632 (US)**

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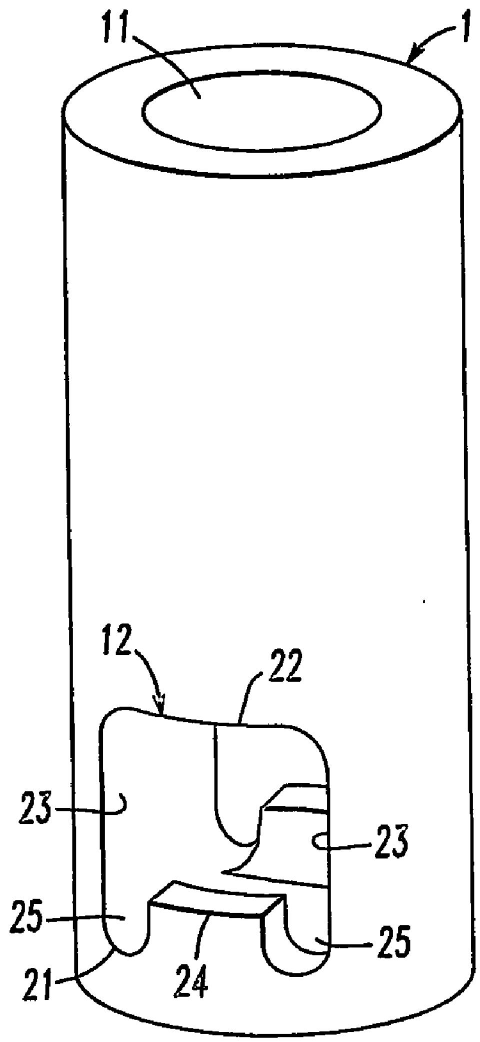
(57) **ABSTRACT**

The present invention relates to a pour tube for casting molten metal. The pour tube is adapted to reduce turbulence and mold disturbances, thereby producing a more stable, uniform outflow. The pour tube includes an exit port with at least one tongue to provide at least two slots on either side of the tongue. The slots generate counter-rotating flows, which result in a more diffusive and more homogeneous outflow. Advantageously, such an outflow can reduce detrimental asymmetry and alumina clogging in the pour tube.



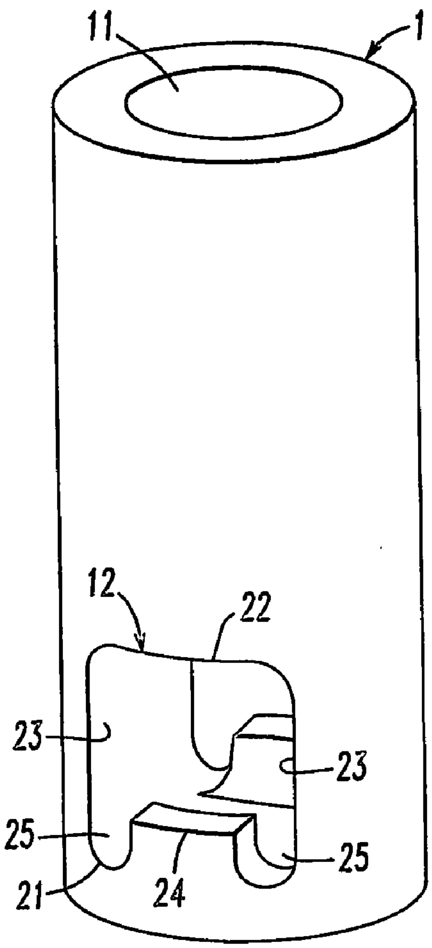



FIG. 1

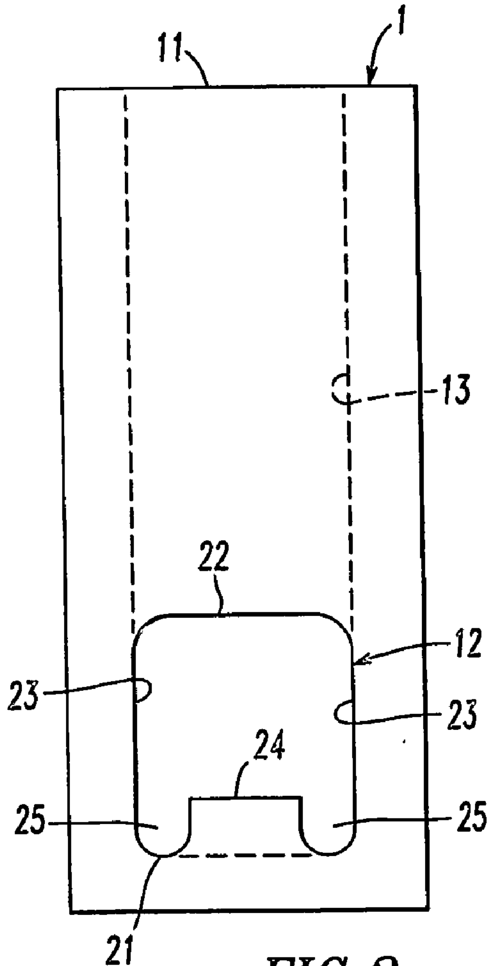



FIG. 2

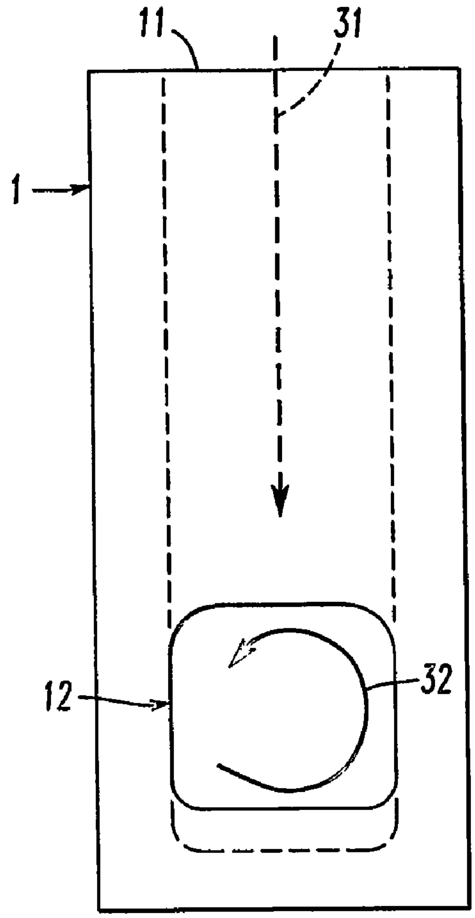



Fig.3

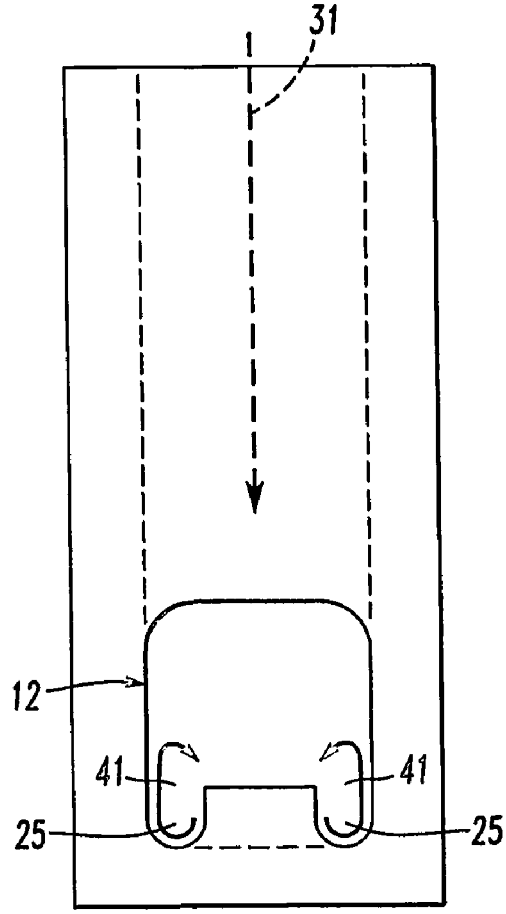
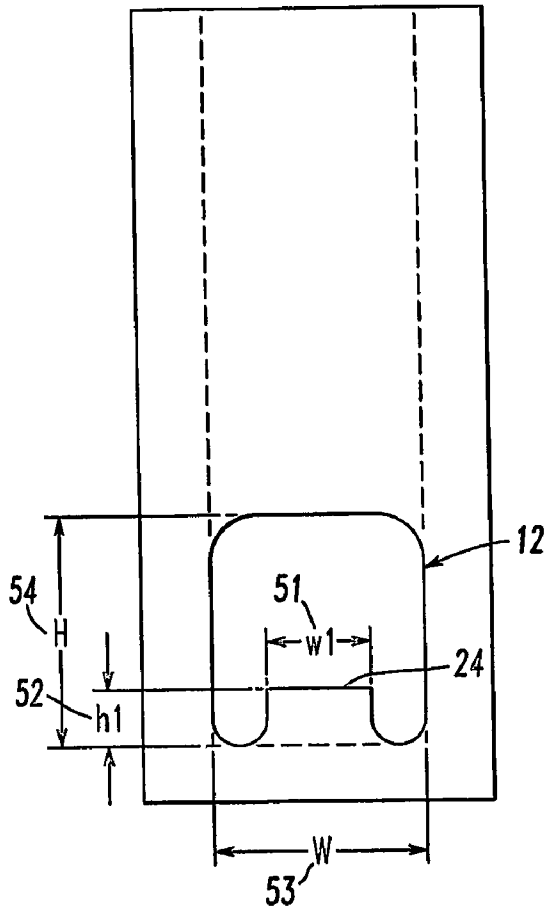



Fig.4

*Fig.5*



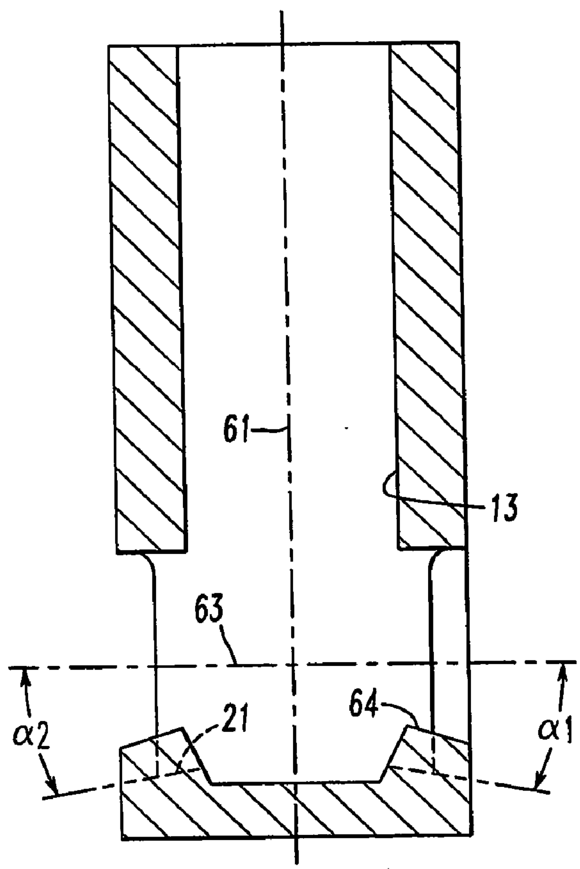




*Fig.6*

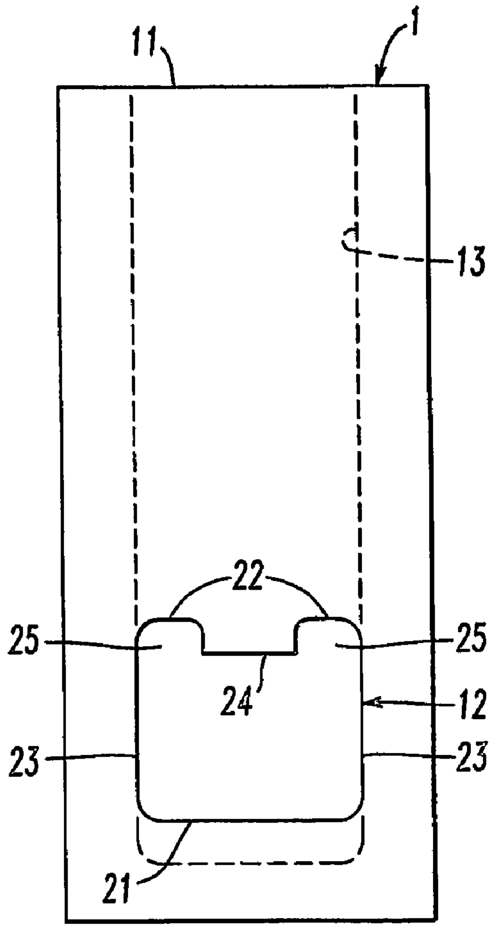



Fig. 7

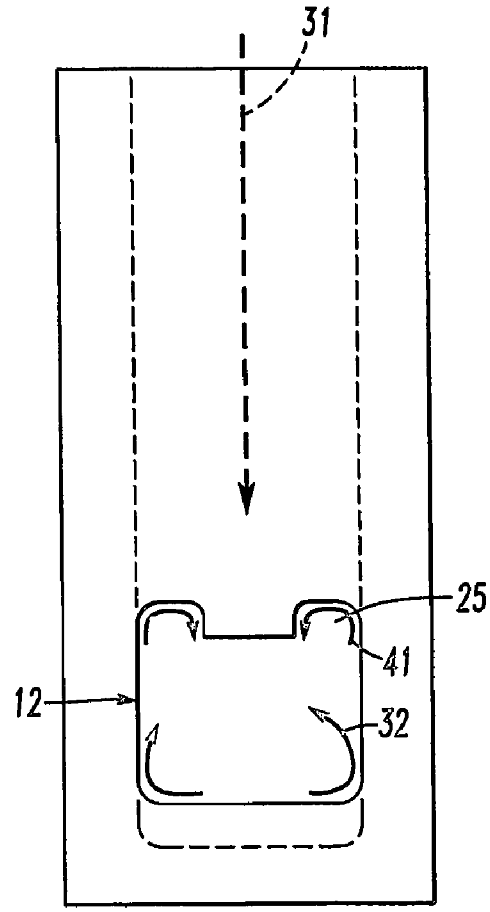



Fig. 8

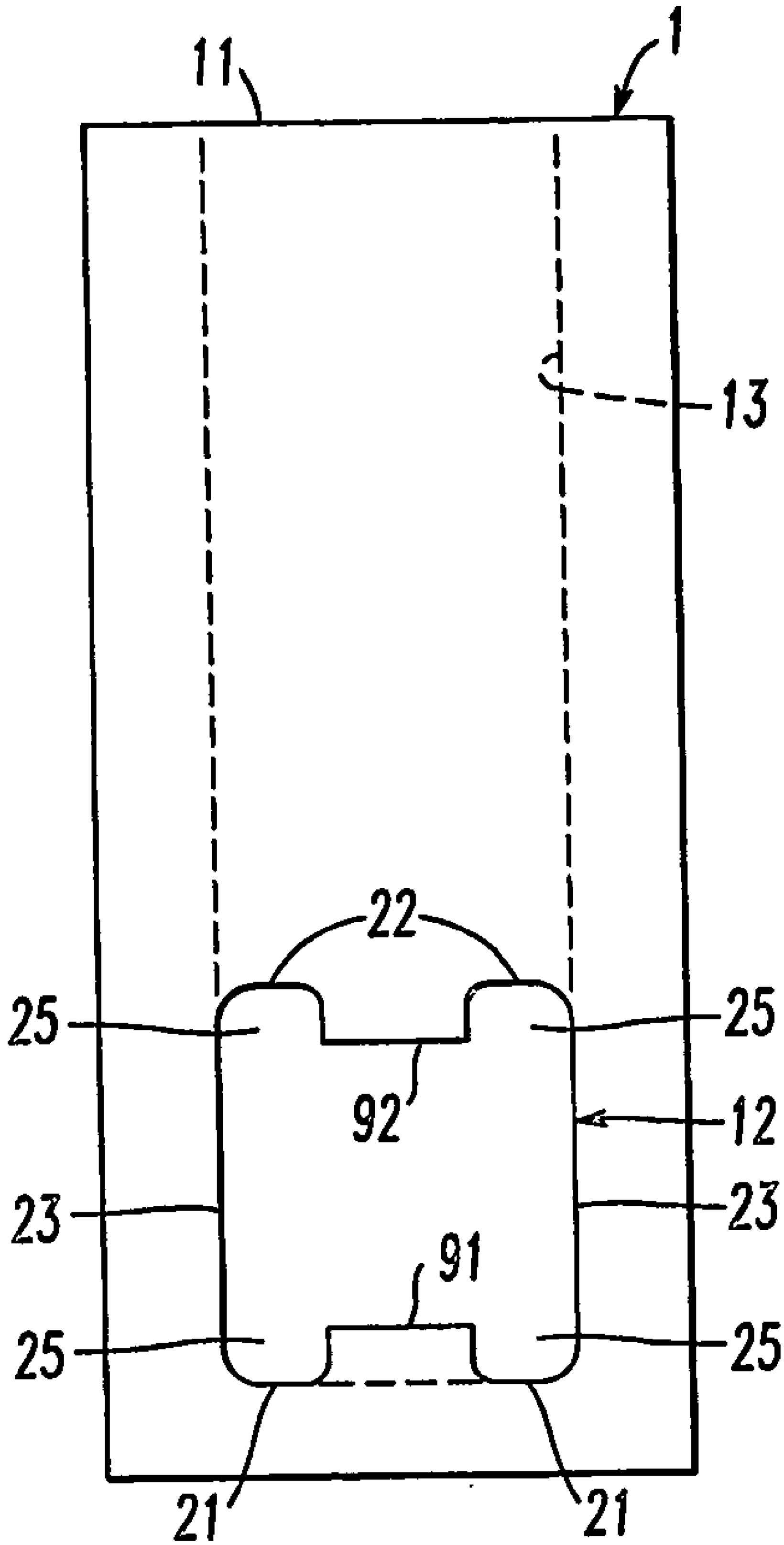



*Fig.9*

# SUBMERGED ENTRY NOZZLE WITH DYNAMIC STABILIZATION

## FIELD OF THE INVENTION

[0001] This invention relates generally to a refractory article and, more particularly, to a refractory pour tube for use in the transfer of molten metal in a continuous casting operation.

## BACKGROUND

[0002] In the continuous casting of metal, particularly steel, a stream of molten metal is typically transferred via a refractory pour tube from a first metallurgical vessel into a second metallurgical vessel or mold. Such tubes are commonly referred to as nozzles or shrouds and possess a bore adapted to transfer molten metal. Pour tubes include submerged-entry nozzles (SEN) or submerged-entry shrouds (SES), which discharge molten metal below the liquid surface of a receiving vessel or mold.

[0003] Liquid metal is discharged from the downstream end of the bore through one or more outlet ports. One important function of a pour tube is to discharge the molten metal in a smooth and steady manner without interruption or disruption. A smooth, steady discharge facilitates processing and can improve the quality of the finished product. A second important function of a pour tube is to establish proper dynamic conditions within the liquid metal in the receiving vessel or mold in order to facilitate further processing. Producing proper dynamic conditions may require the pour tube to possess a plurality of exit ports that are arranged so as to cause the stream of molten metal to be turned in one or more directions upon discharge from the tube.

[0004] Factors, which can disrupt a smooth and steady discharge, include both physical and dynamic conditions that result in asymmetrical flow behavior of the molten metal in the bore and in the exit ports. Asymmetries in the metal flow velocity distribution and streamlines can result from, for example, (a) an ineffective design of the bore and ports, (b) the presence of upstream flow-rate control devices, and (c) the non-uniform build-up of clogging material within the bore and ports. Even in the absence of these factors, turbulent flow in the bore may still cause the development of dynamic flow asymmetries. For example, while flowing through a bore, a molten metal stream may develop higher fluid velocity near the centerline of the bore than along the sides of the bore, or lower velocity on one side of the centerline as compared to the opposite side, or higher fluid velocity off the centerline. Such disparate velocities can cause pulsing and excessive turbulence upon exiting the bore, thereby complicating processing and decreasing the quality of the finished product. Throttling devices, such as stopper rods or slide-gate valves, can partially obstruct the entrance to the bore, and cause the steam of molten metal to enter the bore off the centerline. The stream can flow preferentially down one side of the bore, and exit asymmetrically or non-uniformly from the pour tube causing excessive surging and turbulence in a mold. Pulsing, surging, turbulence and asymmetry of the discharged flow are aggravated by port arrangements that cause the stream to turn before being discharged from the tube. Asymmetries in the streaming flow approaching an exit port can induce unstable spinning and swirling of the turned flow as it is discharged through the ports causing instability of the discharge direction, instability of the pattern of flow induced within the receiving vessel, and thus undesirable dynamic conditions in the receiving vessel.

[0005] Precipitates or non-metallic build-ups may also clog or restrict the bore so as to disrupt steady discharge of molten metal from the tube. In molten steel, precipitates and non-metallic build-ups consist primarily of alumina and other high melting point impurities. Alumina deposits can lead to restrictions and clogging that can stop or substantially impede the smooth and steady flow of liquid steel. Asymmetrical non-uniform metal flow can lead to the presence of preferential sites for clogging deposits and can further exacerbate flow non-uniformity. Tubes may be unclogged using an oxygen lance; however, lancing disrupts the casting process, reduces refractory life, and decreases casting efficiency and the quality of the steel produced. Total or substantial blockage of the bore by precipitates decreases the expected life of the pour tube and is very costly and time-consuming to steel producers.

[0006] Prior art attempts to improve flow include both chemical and mechanical means. For example, flow may be improved by reducing alumina precipitation and subsequent clogging. Prior art has injected gas to pressurize the pour tube and reduce alumina clogging. Unfortunately, gas injection requires large volumes of gas, complicated refractory designs, and is not always an effective solution. Gas may also dissolve or become entrapped within the metal causing problems in metal quality including pinhole or porosity defects in the steel. Alternatively or in combination with gas injection, prior art has lined the bore with refractory compositions that are claimed to resist alumina buildup. Compositions include lower melting point refractories, such as $CaO—MgO—Al_2O_3$ eutectics, calcium zirconate and calcium silicide, that slough off as alumina deposits on the surface. These compositions tend to crack at high temperature, and, during casting, they may de-hydrate and dissipate. For these reasons, their useful life is limited. Other surface compositions that claim to inhibit alumina deposition include refractories containing SiAlON-graphite, metal diborides, boron nitrides, aluminum nitride, and carbon-free compositions. Such refractories can be expensive, impractical, and manufacturing can be both hazardous and time consuming.

[0007] Mechanical designs for improving flow include U.S. Pat. No. 5,785,880 to Heaslip et al., which teaches a pour tube having a diffusing geometry that smoothly delivers a stream of molten metal to a mold. Alternative designs include EP 0 765 702 B1, which describes a perforated obstacle inside the bore that deflects the stream from a preferred trajectory. Both references attempt to control the introduction of molten metal into a mold by mechanically manipulating the stream of molten metal. Neither describes alumina clogging or the reduction of alumina clogging.

[0008] Prior art also includes designs that claim to improve flow by reducing alumina deposition in the bore. These designs include pour tubes with both conical and "stepped" bores. U.S. Pat. No. 4,566,614 to Frykendahl teaches an inert gas-injection nozzle having a conical bore intended to reduce "pulsations" in the gas flow. Smoother gas flow into the bore is said to reduce clogging. "Stepped" designs include pour tubes that have discontinuous changes in bore diameter. Stepped designs also include pour tubes having a spiral bore. JP Kokai 61-72361 is illustrative of stepped pour tubes, and describes a pour tube having a bore with at least one convex or concave section that generates turbulent flow in the molten metal. Turbulent flow, as contrasted with laminar flow, is described as reducing alumina clogging. U.S. Pat. No. 5,328,064 to Nanbo et al. teaches a bore having a plurality of concave sections separated by steps having a constant diameter, d. Each section has a diameter greater than d, and preferably the diameters of the sections decrease along the direction of flow. The steps are described as generating turbulence that reduces alumina clogging.

**[0009]** U.S. Pat. No. 6,425,505 to Heaslip teaches a pour tube comprising a plurality of fluidly connected sections that improve the flow of molten metal through the bore. The sections reduce asymmetric flow of the molten metal stream and the likelihood of precipitates clogging the bore. Each section comprises a converging portion and a diverging portion. The converging portion deflects the stream toward the center of the bore, while the diverging portion diffuses the stream. The combination of converging and diverging elements produce a more symmetrical flow in the pour tube.

**[0010]** Prior art attempts to control the flow of molten metal within the bore have done little to control unsteady flow from the exit ports of the pour tube. The exit ports induce unstable flow patterns in the outflow stream. Non-steady flow from the pour tube into a mold can increase meniscus turbulence and waving. Such flow can also cause the outflow stream to wander in the mold and can bias the flow pattern in the mold. Further, unstable outflow can cause alumina clogging in the lower regions of the pour tube, including the well bottom of the tube and the lower corners of the ports. Clogging will typically impart an asymmetrical outflow from the pour tube.

**[0011]** A need persists for a refractory pour tube that produces a stable outflow and reduces meniscus turbulence, waving, asymmetrical flow patterns, and alumina clogging. Ideally, such a tube would also improve the flow of molten metal into a casting mold and improve the properties of the cast metal.

## SUMMARY OF THE INVENTION

**[0012]** The present invention relates to a pour tube for use in the casting of molten metal. The pour tube includes at least one exit port and, relative to prior art, provides a more stable, uniform outflow of molten metal through and from the exit port. Improved outflow reduces meniscus turbulence and waving, reduces alumina clogging, and promotes symmetrical outflow. These benefits can result in an improved finished product.

**[0013]** In a broad aspect, the article comprises a pour tube having an exit port shape that reduces flow instability, thereby producing a steadier outflow. This shape reduces the unstable back-and-forth spinning flow pattern that is common in outflow streams from a pour tube. This flow pattern is described as at least partially responsible for mold flow instabilities and poor quality castings.

**[0014]** In one aspect, the invention includes an exit port that stabilizes and controls spinning or rotating of the flow as the flow passes through an outlet port and discharges into the mold. Large-scale spinning whereby the circumference of the rotating flow approaches the width or height of an outlet port is opposed and thereby reduced. Unstable and uncontrolled large-scale spinning of the discharge flow is believed to cause more wandering and instability of the flow pattern generated in the mold or receiving vessel. The exit port includes a plurality of slots that produce consistent counter-rotating flows in the molten metal and that oppose large-scale spinning of the flow in a single direction or large-scale flow spinning that oscillates from one direction to the opposite direction. Stable counter-rotating flows within the outflow from the tube provide a more diffusive, homogeneous, and less turbulent discharge of molten metal and thereby provide a more consistent flow pattern in the receiving vessel.

**[0015]** The outflow from a pour tube may form a portion of an upper circulation loop within a mold. The upper circulation loop is proximate to the upper surface of the mold and affects, for example, top surface waving and meniscus turbulence. The outflow from an exit port of the present invention can direct more molten metal to the surface of the mold without causing excessive meniscus turbulence or mold level fluctuation. Thermal distribution within the mold may also be improved. The overall flow pattern within the mold becomes more stable.

**[0016]** In one embodiment, the exit port includes a tongue on its downstream edge.

**[0017]** The tongue, and the downstream edge define slots in the lower corners of the exit port. The presence of these slots opposes large-scale spinning of the discharge flow and promotes the formation of small-scale counter-rotating flows within the outflow from the tube. An exit port comprising a tongue alters the pressure and flow characteristics within an exit port and within the outlet region of the pour tube, so that alumina clogging and asymmetric flow is reduced.

**[0018]** In a second embodiment, the exit port includes a tongue on its upstream edge. The tongue, and the upstream edge define slots in the upper corners of the exit port. The presence of these slots opposes large-scale flow spinning within the outflow. Large scale spinning is undesirable as such spinning is inherently unstable and generally exhibits occasional switching of direction, providing inconsistent direction of discharge and unstable dynamic behavior in the discharge flow and subsequently in the mold.

**[0019]** In a third embodiment, the exit port includes tongues on both the upstream and downstream edges of the port. An exit port comprising both upstream and downstream tongues promotes the formation of steady counter-rotating flows within the outflow with excellent symmetry and of small and controlled scale.

**[0020]** Other details, objects and advantages of the invention will become apparent as the following description of a present preferred method of practicing the invention proceeds.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0021]** **FIG. 1** shows a three-dimensional view of a first embodiment of a pour tube of the current invention.

**[0022]** **FIG. 2** shows a view of a first embodiment of a pour tube of the present invention from a view perpendicular to an exit port.

[0023] **FIG. 3** shows a view of a pour tube of prior art from a view perpendicular to an exit port and the incident unstable flow pattern.

[0024] **FIG. 4** shows a view of a first embodiment of a pour tube of the present invention including counter-rotating flow pattern.

[0025] **FIG. 5** shows a view of a first embodiment of a pour tube of the present invention defining the design parameters of a tongue.

[0026] **FIG. 6** shows a sectional view of a first embodiment of a pour tube of the present invention sectioned transversely defining the discharge angles of slots and tongue.

[0027] **FIG. 7** shows a view of a second embodiment of a pour tube of the present invention from a view perpendicular to an exit port.

[0028] **FIG. 8** shows a view of a second embodiment of a pour tube of the present invention from a view perpendicular to an exit port including counter-rotating flow pattern.

[0029] **FIG. 9** shows a view of a third embodiment of a pour tube of the present invention from a view perpendicular to an exit port.

## DETAILED DESCRIPTION OF INVENTION

[0030] The invention comprises a pour tube for use in the continuous casting of molten metal. The pour tube comprises a bore fluidly connected to at least one exit port. Pour tube means shrouds, nozzles, and other refractory pieces for directing a stream of molten metal, including, for example, submerged entry shrouds and nozzles. The invention is particularly suited for pour tubes having an exit port adapted to deliver molten metal below the surface of the metal in a receiving vessel such as a mold.

[0031] **FIGS. 1 and 2** show alternative perspectives of a pour tube **1**. The pour tube **1** comprises an inlet **11** and an exit port **12** fluidly connected by a bore **13**. The pour tube **1** permits a stream of molten metal to pass from an upstream end at the inlet **11**, through the bore and to a downstream end at the exit port **12**. The exit port **12** is defined by the perimeter of a hole that extends through the pour tube **1** from its outer surface to its bore **13**. The perimeter of the exit port **12** comprises a downstream surface **21**. The perimeter of the exit port may be of any convenient general shape including, but not limited to, oval, polygonal or any combination thereof. Conveniently, the general shape of the exit port is substantially rectangular. In one embodiment, the exit port **12** is defined by the downstream surface **21**, an upstream surface **22**, and side surfaces **23** connecting the downstream and upstream surfaces. At least one tongue **24** extends from either the downstream surface **21** or upstream surface **22**. The tongue **24**, downstream surface **21** and side surfaces **23** define a plurality of slot-shaped openings **25**.

[0032] **FIG. 3** shows a pour tube **2** of the prior art with inlet **11** and exit port **12**. During the casting of molten metal, at least a portion of the kinetic energy of a downward stream **31** of molten metal translates into a rotating outflow **32** having an angular momentum. The remaining kinetic energy causes the stream to exit the exit port as a high velocity jet. Rotating outflow **32** is shown to be spinning in a counter-clockwise direction as viewed, but the spinning direction of the outflow from a pouring tube of the prior art is unstable and will exhibit occasional switching of direction. Depending on the degree of asymmetry of the momentum distribution within downward stream **31**, the scale of the spinning in the outflow can be as great as the width, and the height, or the diameter of the exit port. Unstable large-scale spinning within the outflow and the high velocity jet produced by prior art pour tubes result in turbulence, surface waving, flow pattern instability and thermal inhomogeneities within the mold. Further compounding these difficulties, rotational flow **32** causes flow separation within the exit port **12**. Flow separation is associated with alumina clogging, which can block the outflow from the exit port. The combination of a high velocity jet and large-scale rotational flow produces an unstable outflow that can oscillate and wander within the mold. Exit ports of the prior art do not correct these deficiencies.

[0033] In contrast, the exit port **12** of the present invention, as shown in **FIG. 4**, redirects the downward stream **31** of molten metal at least partially through the slots **25**. The slots translate at least a portion of the kinetic energy of the downward stream **31** into at least two counter-rotating flows **41** and thus oppose formation of a single large-scale spinning loop within the outflow. The angular momentums of the counter-rotating flows **41** substantially cancel so that the outflow from the exit port **12** has little or no net angular momentum. Simultaneously, the kinetic energy and consequently the velocity of the discharged flow are substantially reduced since the discharged flow is more uniformly distributed throughout exit port **12**. Counter-rotating flows **41** permit the velocity of the outflow to be substantially reduced and large-scale spinning, swirling or vortexing in the outflow to be inhibited. Outflow is more diffusive and can be directed closer to the surface without causing surface waving or turbulence. A more diffusive outflow results in better thermal distribution in a mold. Additionally, flow separation in the exit port **12** and the associated alumina clogging are reduced. Flow instabilities inherent in alumina clogging may be substantially avoided.

[0034] A tongue should be of a sufficient size to define slots capable of inducing counter-rotating flows in the outflow. Referring to **FIG. 5**, the tongue **24** has a width (w**1**) **51** and a height (h**1**) **52**. In relation to the width (W) **53** and height (H) **54** of the exit port **12**, the width **51** of the tongue will typically be at least about one-eighth of the exit port's width **53**. The height **52** of the tongue will commonly be at least about one-eighth the height **54** of the exit port **12**. Obviously, increasing the dimensions of the tongue can reduce the total discharge area of the exit port, thereby reducing the possible outflow from the pour tube, so the tongue will often be as small as possible to produce the counter-rotating flows. Casting conditions, including the grade of molten metal, casting temperature, mold geometry, volume of outflow, size of the pour tube, and size of the exit port, will affect the dimensions of the tongue.

[0035] Referring to **FIG. 6**, the tongue and its associated slots are designed to turn the discharge flow to a desired angle. Longitudinal axis **61** of the bore **13** is aligned with the general direction of the downward metal flow through the bore. Perpendicular axis **63** is at a right angle to longitudinal axis **61** and passes generally centrally through an exit port. The surface of the tongue away from the edge is defined as the extended surface **64**, and is arranged at angle $\alpha_2$ to perpendicular axis **63**. Downstream surface **65** of a slot is arranged at angle $\alpha_2$ to perpendicular axis **63**. Angles $\alpha_1$ and $\alpha_2$ can be chosen to turn portions of the discharge flow to the desired angles of discharge. As known to those skilled in the art, the desired angles of discharge will depend on the casting conditions, such as grade of molten metal, casting temperature, mold geometry, volume of outflow, size of the pour tube, and size of the exit port. The angles $\alpha_1$ and $\alpha_2$ typically range from −45 to +45 degrees.

[0036] **FIG. 7** shows a second embodiment of a pour tube of the present invention. The pour tube **1** comprises an inlet **11** and an exit port **12** fluidly connected by a through-flow bore **13**. The pour tube **1** is adapted to transport a stream of molten metal from an upstream end at the inlet **11**, through the bore, and to a downstream end comprising the exit port **12**. The exit port **12** is defined by an upstream surface **22**, a downstream surface **21**, and side surfaces **23** connecting the downstream and upstream surfaces. The exit port may be of any convenient general shape including, but not limited to, oval, polygonal or any combination thereof. Conveniently, the general shape of the exit port is substantially rectangular. At least one tongue **24** extends downstream from the upstream surface **22**. The tongue **24**, upstream surface **22** and side surfaces **23** define a plurality of slot-shaped openings **25**.

[0037] An exit port **12** of the present invention, as shown in **FIG. 8**, redirects the downward stream **31** of molten metal at least partially through the slots **25**. By opposing formation of a single large-scale spinning loop within the discharging flow, the slots **25** translate at least a portion of the kinetic energy of the spinning flows **32** into counter-rotating flows **41**. The angular momentums of the counter-rotating flows **41** substantially reduce the angular momentum of the outflow from the exit port **12**. Large-scale spinning, swirling or vortexing in the outflow is inhibited and the outflow is more symmetric, more diffusive and can be directed closer to the top surface of the mold or receiving vessel without excessive surface waving or turbulence. Additionally, flow separation in the exit port **12**, flow instabilities inherent in alumina clogging may be substantially avoided, and the associated alumina clogging may be reduced.

[0038] **FIG. 9** shows a third embodiment of a pour tube of the present invention. The pour tube **1** comprises an inlet **11** and exit port **12** fluidly connected by a through-flow bore **13**. The pour tube **1** is adapted to transport a stream of molten metal from an upstream end at the inlet **11**, through the bore, and to a downstream end comprising the exit port **12**. The exit port **12** is defined by an upstream surface **22**, a downstream surface **21**, and side surfaces **23** connecting the downstream and upstream surfaces. The exit port may be of any convenient general shape including, but not limited to, oval, polygonal or any combination thereof. Conveniently, the general shape of the exit port is substantially rectangular. At least one lower tongue **91** extends upstream from the downstream surface **21** and at least one upper tongue **92** extends downstream from the upstream surface **22**. The lower tongue **91**, the upper tongue **92**, downstream surface **21**, upstream surface **22** and side surfaces **23** define a plurality of slot-shaped openings **25**. Molten metal being discharged from pour tube **1** passes at least partially through the slots **25** with formation of counter-rotating flows of small-scale and very high stability. Obviously, numerous modifications and variations of the present invention are possible. Advantageously, the present invention may be combined with bore geometries of the prior art such as, for example, bores comprising discontinuities or "steps," or bores comprising frusto-conical sections. It is, therefore, to be understood that within the scope of the following claims, the invention may be practiced otherwise than as specifically described.

What is claimed is:

**1-12**. (canceled)

**13**. A pour tube for use in casting a stream of molten metal from an upstream position to a downstream position, the pour tube comprising an inner surface defining a bore and an outer surface having at least one exit port defined at least partially by an edge and fluidly connected to the bore, wherein the exit port includes at least one tongue extending from an edge, whereby at least two slots are created in the exit port.

**14**. The pour tube of claim 13, wherein the exit port includes a downstream edge and the tongue extends upstream from the downstream edge.

**15**. The pour tube of claim 13, wherein the exit port includes an upstream edge and the tongue extends downstream from the upstream edge.

**16**. The pour tube of claim 13, wherein the exit port includes an upper tongue extending downstream from an upstream edge and a lower tongue extending upstream from a downstream edge.

**17**. The pour tube of claim 13 wherein the pour tube includes a longitudinal axis between the upstream and downstream positions.

**18**. The pour tube of claim 17, wherein at least one tongue includes an extended surface, and the extended surface defines a tongue plane that intersects the longitudinal axis at an angle from −45 to +45 degrees.

**19**. The pour tube of claim 17, wherein at least one edge includes an edge surface defining an edge plane that intersects the longitudinal axis at an angle from −45 to +45 degrees.

**20**. The pour tube of claim 17, wherein the exit port defines an exit plane substantially parallel to the longitudinal axis.

**21**. The pour tube of claim 13, wherein the bore comprises a plurality of fluidly connected sections.

**22**. The pour tube of claim 21, wherein a discontinuity separates each section.

**23**. The pour tube of claim 21, wherein the sections include at least one frusto-conical section.

**24**. A method of casting a stream of molten metal using a pour tube as described in any one of claims **13-23**, comprising:

a) flowing a stream of metal through the bore;

b) directing the stream towards the exit port; and

c) producing symmetric counter-rotating currents in the stream as the stream passes through the exit port.

* * * * *