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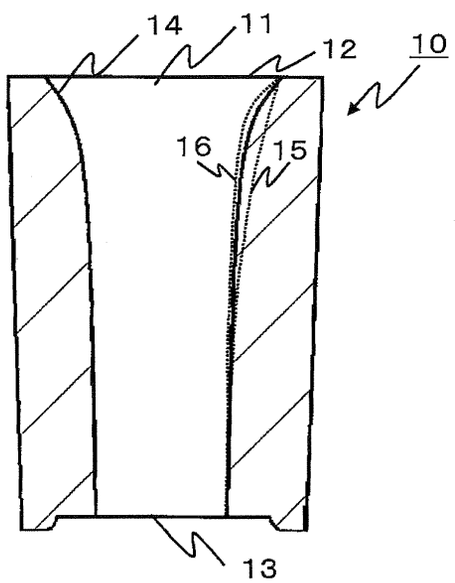
(54) NOZZLE FOR DISCHARGING MOLTEN METAL

(57) Provided is a molten metal discharge nozzle which has a bore configuration capable of creating a low-energy loss and smooth (stabilized) molten metal flow to suppress the occurrence of an adhesion matter. In the molten metal discharge nozzle, a radius r(0) of an upper end (12) of a bore (11) thereof is 1.5 times or more a radius r(L) of a lower end (13) of the bore, and a cross-sectional shape of a bore wall surface 14 taken along an axis of the bore has no bend point. Further, a radius r(z) of the bore at a position downwardly away from the upper end of the bore by a distance z (where L is an axial length of the bore) is in a range between $[[L/\{(r(0)/r(L))^{1.5} - 1\} + L] / [L/((r(0)/r(L))^{1.5} - 1\} + z]]^{1/1.5} \times r(L)$ and $[[L/\{(r(0)/r(L))^{6} - 1\} + L] / [L/\{(r(0)/r(L))^{6} - 1\} + z]]^{1/6} \times r(L)$.

Fig.1



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Description

TECHNICAL FIELD

[0001] The present invention relates to a molten metal discharge nozzle designed to be installed in a bottom of a molten metal vessel to discharge molten metal from the molten metal vessel, and configured such that it has in an axial direction thereof a bore for allowing passage of molten metal,.

BACKGROUND ART

[0002] To explain a molten metal discharge nozzle by taking as an example an upper nozzle designed to be fitted into a discharge opening of a tundish or a ladle, alumina and other inclusions are apt to adhere to a wall surface of a bore of the upper nozzle for allowing passage of molten metal to form an adhesion matter thereon, which narrows a flow passage to hinder a casting operation, or is likely to fully clog the flow passage to preclude the casting operation. As means for preventing the occurrence of such an adhesion matter, for example, a method has been proposed which is intended to provide a gas injection port to inject an inert gas (see, for example, the following Patent Document 1 or 2).

[0003] However, due to a mechanism for gas injection, an upper nozzle disclosed in the Patent Document 1 or 2 has a complicated structure which requires time-consuming fabrication, and it is necessary to supply gas during a casting operation, which leads to an increase in cost. Moreover, even if the gas injection-type nozzle is employed, it is difficult to completely prevent the occurrence of the adhesion matter.

[0004] Meanwhile, a widely used type of upper nozzle includes, for example, a type consisting of a reverse taper region formed on an upper (upstream) side thereof and a straight region formed on a lower (downstream) side thereof (see FIG. 8(a)), and a type having an arc-shaped region continuously extending from the reverse taper region and the straight region (see FIG. 9(a)). In FIGS. 2 to 9, each diagram suffixed by (a) illustrates an upper nozzle under the condition that it is installed in a sliding nozzle device (hereinafter referred to as "SN device"), wherein a region downward (downstream) of the one-dot chain line is a bore of an upper plate, and a region downward of a position where two bores are out of alignment is a bore of an intermediate plate or a lower plate.

[0005] A distribution of pressures to be applied to a wall surface of a bore in an upper nozzle (length: 230 mm) having the configuration illustrated in FIG. 8(a) during passage of molten steel through the bore was calculated (by computer simulation-based fluid analysis). As a result, it was ascertained that the pressure is rapidly changed in a region beyond a position (away from an upper (upstream) end of the bore by 180 mm) where the bore wall surface is changed from a reverse taper configuration to a straight configuration, as indicated by the dotted line in FIG. 8(b).

[0006] The computer simulation-based fluid analysis was performed using fluid analysis software (trade name "Fluent Ver. 6.3.26 produced by Fluent Inc.).

Input parameters in the fluid analysis software are as follows:

- The number of calculational cells: about 120,000 (wherein the number can vary depending on a model)
- Fluid: water (wherein it has been verified that the evaluation for molten steel can also be performed in a comparative manner)
  Density = 998.2 kg/m^3
  Viscosity = 0.001003 kg/m·s
- Hydrostatic Head (H'): 1000 mm
- Pressure: Inlet (Molten steel surface) = ((700 + a length (mm) of a nozzle) x 9.8) Pa (gage pressure)

Outlet (Lower end of the nozzle) = 0 Pa

- Length of Nozzle: 230 mm
- Viscous Model: K-omega calculation

[0007] Further, a distribution of pressures to be applied to a wall surface of a bore in an upper nozzle (length: 230 mm) having the configuration illustrated in FIG. 9(a) during passage of molten steel through the bore was calculated. As a result, it was ascertained that the pressure is changed in an arc curve, i.e., a pressure change is not constant, as illustrated in FIG. 9(b), although the rapid pressure change is suppressed as compared with the upper nozzle in which the bore wall surface is changed from the reverse taper configuration to the straight configuration, as illustrated in FIG. 8(a). In FIGS. 2 to 9, a region rightward of the one-dot chain line in each graph suffixed by (b) indicates pressures to be applied to the bore wall surface of the upper plate.

[0008] The rapid pressure change and the arc-curved pressure change are caused by a phenomenon that a molten steel flow is changed along with a change in configuration of the bore wall surface from the reverse taper configuration

to the straight configuration. In a swirling nozzle adapted to intentionally change a molten steel flow, an adhesion matter is observed around a position where the molten steel flow is changed. Thus, it is considered that an adhesion matter on the bore wall surface can be suppressed by creating a smooth molten steel flow, i.e., a molten steel flow having an approximately constant pressure change with respect to the bore wall surface.

[0009] As a technique for stabilizing a molten steel flow, an invention concerning a configuration of a bore of a tapping tube for a converter has been proposed (see, for example, the following Patent Document 3).

[0010] However, a technique disclosed in the Patent Document 3 is intended to prevent a vacuum area from being formed in a central region of a molten steel flow so as to suppress entrapment of slag and incorporation of oxygen, nitrogen, etc., but it is not intended to prevent the occurrence of the adhesion matter. Further, the technique disclosed in the Patent Document 3 is designed for a converter (refining vessel), wherein the effect of preventing entrapment of slag, etc., becomes important in a last stage of molten steel discharge (assuming that a tapping time is 5 minutes, the last stage is about 1 minute). On the other hand, in order to prevent the occurrence of the adhesion matter in a ladle or a tundish (casting or pouring vessel), it is necessary to bring out an intended effect particularly in a certain period other than the last stage of molten steel discharge, i.e., a desired period for bringing out the intended effect is different.

LIST OF PRIOR ART DOCUMENTS

[PATENT DOCUMENTS]

[0011]

Patent Document 1: JP 2007-090423A

Patent Document 2: JP 2005-279729A

Patent Document 3: JP 2008-501854A

SUMMARY OF THE INVENTION

[PROBLEM TO BE SOLVED BY THE INVENTION]

[0012] It is therefore an object of the present invention to provide a molten metal discharge nozzle having a bore configuration capable of facilitating stabilization of a pressure to be applied from an outer peripheral region of a molten metal flow onto a bore wall surface, so as to create a low-energy loss and smooth molten metal flow to suppress the occurrence of an adhesion matter.

[MEANS FOR SOLVING THE PROBLEM]

[0013] The present invention provides a molten metal discharge nozzle having in an axial direction thereof a bore for allowing passage of molten metal, wherein: a radius r(0) of an upper end of the bore is 1.5 times or more a radius r(L) of a lower end of the bore; a line indicative of a wall surface of the bore in a cross-section taken along an axis of the bore has no bend point; a radius r(1/4L) of the bore at a position downwardly away from the upper end of the bore by a distance r(1/4L) of the bore at a position downwardly away from the upper end of the bore by a distance of 1/4L (where L is an axial length of the bore) is in a range between $[[L/\{(r(0)/r(L))^{1.5} - 1\} + L] / [L/\{(r(0)/r(L))^{1.5} -1\} + 1/4\ L]\ ]^{1/1.5} \times r(L)$ and $[\ [L/\{(r(0)/r(L))^{6} - 1\} + L] / [L/\{(r(0)/r(L))^{6} - 1\} + 1/4\ L]\ ]^{116} \times r(L)$; a radius r(1/2L) of the bore at a position downwardly away from the upper end of the bore by a distance of 1/2L is in a range between $[\ [L/\{(r(0)/r(L))^{1.5} - 1\} + L] /[L/\{(r(0)/r(L))^{1.5} - 1\} + 1/2\ L]\ ]^{1/1.5} \times r(L)$ and $[[L/\{(r(0)/r(L))^{6} -1\} + L] / [L/\{(r(0)/r(L))^{6} - 1\} + 1/2\ L]]^{1/6} \times r(L)$; and a radius r(3/4L) of the bore at a position downwardly away from the upper end of the bore by a distance of 3/4L is in a range between $[[L/\{(r(0)/r(L))^{1.5} - 1\} + L] /[L/\{(r(0)/r(L))^{1.5} - 1\} + 3/4\ L]]^{1/1.5} \times r(L)$ and $[[L/\{(r(0)/r(L))^{6} - 1\} + L] / [L/\{(r(0)/r(L))^{6} -1\} + 3/4\ L]]^{1/6} \times r(L)$.

[EFFECT OF THE INVENTION]

[0014] The molten metal discharge nozzle of the present invention can suppress the occurrence of an adhesion matter on the wall surface of the bore during passage of molten metal therethrough.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015]

FIG. 1 is a vertical cross-sectional view illustrating one example of an upper nozzle according to the present invention.
FIGS. 2(a) and 2(b) are, respectively, a diagram illustrating a configuration of an upper nozzle, and a graph illustrating a pressure distribution during passage of molten steel through the upper nozzle, wherein n = 4.
FIGS. 3(a) and 3(b) are, respectively, a diagram illustrating a configuration of an upper nozzle, and a graph illustrating a pressure distribution during passage of molten steel through the upper nozzle, wherein n = 6.
FIGS. 4(a) and 4(b) are, respectively, a diagram illustrating a configuration of an upper nozzle, and a graph illustrating a pressure distribution during passage of molten steel through the upper nozzle, wherein n = 1. nozzle, and a graph illustrating a pressure distribution during passage of molten steel through the upper nozzle, wherein n = 7.
FIGS. 6(a) and 6(b) are, respectively, a diagram illustrating a configuration of an upper nozzle, and a graph illustrating a pressure distribution during passage of molten steel through the upper nozzle, wherein n = 4, and a radius ratio = 1.5.
FIGS. 7(a) and 7(b) are, respectively, a diagram illustrating a configuration of an upper nozzle, and a graph illustrating a pressure distribution during passage of molten steel through the upper nozzle, wherein the radius ratio = 1.
FIGS. 8(a) and 8(b) are, respectively, a diagram illustrating a configuration of a conventional upper nozzle, and a graph illustrating a pressure distribution during passage of molten steel through the conventional upper nozzle.
FIGS. 9(a) and 9(b) are, respectively, a diagram illustrating a configuration of a conventional upper nozzle, and a graph illustrating a pressure distribution during passage of molten steel through the conventional upper nozzle.
FIG. 10 is a schematic axial cross-sectional view illustrating a tundish and an upper nozzle.

DESCRIPTION OF EMBODIMENTS

[0016] The present invention will now be specifically described based on an embodiment thereof by taking an upper nozzle as an example.

[0017] FIG. 1 is a cross-sectional view illustrating one example of an upper nozzle according to the present invention, taken along an axial direction of a bore thereof for allowing passage of molten steel. As illustrated in FIG. 1, an upper nozzle 10 according to the present invention is formed with a bore 11 for allowing passage of molten steel, wherein the bore has a large-diameter end 12 adapted to be fitted into a discharge opening of a tundish or a ladle, a small-diameter end 13 adapted to discharge molten steel therefrom, and a bore wall surface 14 continuously extending from the large-diameter end 12 to the small-diameter end 13.

[0018] The upper nozzle 10 according to the present invention is configured such that a radius r(0) of an upper end (large-diameter end 12) of the bore is 1.5 times or more a radius r(L) of a lower end (small-diameter end 13) of the bore, and a line indicative of the bore wall surface 14 in a cross-section taken along an axis of the bore 11 has no bend point. Further, a radius r(1/4L) of the bore 11 at a position downwardly away from the upper end of the bore by a distance of 1/4L, a radius r(1/2L) of the bore at a position downwardly away from the upper end of the bore by a distance of 1/2L, and a radius r(3/4) of the bore at a position downwardly away from the upper end of the bore by a distance of 3/4L (where L is an axial length of the bore 11) are, respectively, in a range between $[[L/((r(0)/r(L))^{15} - 1\} + L] / [L/\{(r(0)/r(L))^{1.5} - 1\} + 1/4\ L]]^{1/1.5} \times r(L)$ and $[[L/\{(r(0)/r(L))^{6} - 1\} + L] / [L/\{(r(0)/r(L))^{6} - 1\} + 1/4\ L]]^{1/6} \times r(L)$, a range between $[[L/\{(r(0)/r(L))^{1.5} - 1\} + L]/[L/((r(0)/r(L))^{1.5} - 1\} + 1/2\ L]]^{1/1.5} \times r(L)$ and $[[L/\{(r(0)/r(L))^{6} - 1\} + L] / [L/\{(r(0)/r(L)\}^{6} -1\} + 1/2\ L]]^{1/6} \times r(L)$, and a range between $[[L/\{(r(0)/r(L)^{1.5} - 1\} + L]/ [L/\{(r(0)/r(L))^{1.5} - 1\} + 3/4\ L]]^{1/1.5} \times r(L)$ and $[[L/\{(r(0)/r(L))^{6} -1\} + L] / [L/\{(r(0)/r(L))^{6} - 1\} + 3/4\ L]]^{1/6} \times r(L)$.

[0019] In FIG. 1, a curve (line) indicated by the reference numeral 15 is a locus of a radius r(z) represented by the following formula:

$$[\ [L/\{(r(0)/r(L))^{1.5} - 1\} + L] / [L/\{(r(0)/r(L))^{1.5} - 1\} + z]\ ]^{1/1.5} \times r(L) \quad \text{--- Formula A}$$

, and a curve (line) indicated by the reference numeral 16 is a locus of a radius r(z) represented by the following formula:

$$[\ [L/\{(r(0)/r(L))^{6} - 1\} + L] / [L/\{(r(0)/r(L))^{6} - 1\} + z]\ ]^{1/6} \times r(L) \quad \text{--- Formula B}$$

[0020] In other words, the present invention requires that: each of three radii r(1/4L), r(1/2L), r(3/4) of the bore at respective points by which the axial length L of the bore is divided into quarters falls within a range between the curve 15 and the curve 16; and the line indicative of the bore wall surface 14 in a cross-section taken along the axis of the bore 11 has no bend point.

[0021] The above requirement for the bore configuration will be more specifically described. On an assumption that a low-energy loss and smooth (constant or stabilized) molten steel flow can be created by stabilizing a pressure distribution on a bore wall surface of an upper nozzle in its height direction, the inventors of this application have found out a bore

configuration of the present invention capable of suppressing a rapid change in pressure on the bore wall surface, as described below.

[0022] Although an amount of molten steel flowing through a bore of an upper nozzle is controlled by an SN device disposed underneath (just downstream of) the upper nozzle, energy for obtaining a flow velocity of molten steel is fundamentally a hydrostatic head of molten steel in a tundish. Thus, a flow velocity v (z) of molten steel at a position away from an upper end of the bore by a distance z is expressed as follows:

$$v(z) = k(2g(H' + z))^{1/2},$$

where: g is a gravitational acceleration;
H' is a hydrostatic head height of molten steel; and
k is a flow coefficient.

[0023] A flow volume Q of molten steel flowing through the bore of the upper nozzle is a product of a flow velocity v of the molten steel and a cross-sectional area A of the bore. Thus, the flow volume Q is expressed as follows:

$$Q = v(L) \times A(L) = k(2g(H' + L))^{1/2} \times A(L),$$

where: L is a length of the bore (a length of the upper nozzle);
v (L) is a flow velocity of molten steel at a lower end of the bore;
A (L) is a cross-sectional area of the lower end of the bore; and
g is a gravitational acceleration.

[0024] Further, the flow volume Q is constant, irrespective of a position of a cross-section of the bore taken along a direction perpendicular to an axis of the bore. Thus, a cross-sectional area A(z) at a position away from the upper end of the bore by a distance z is expressed as follows:

$$A(z) = Q / v(z) = k(2g(H' + L))^{1/2} \times A(L) / k(2g(H' + z))^{1/2}$$

This formula can be expressed as follows by dividing each of the left-hand and right-hand sides by A (L):

$$A(z) / A(L) = ((H' + L) / (H' + z))^{1/2}$$

[0025] In the above formula, $A(z) = \pi r(z)^2$, and $A(L) = \pi r(L)^2$, where is a ratio of the circumference of a circle to its diameter. Thus, the above equation is expressed as follows:

$$A(z) / A(L) = \pi r(z)^2 / \pi r(L)^2 = ((H' + L) / (H' + z))^{1/2}$$

$$r(z) / r(L) = ((H' + L) / (H' + z))^{1/4}$$

[0026] Thus, a radius r (z) of the bore at an arbitrary position is expressed as follows:

$$r(z) = ((H' + L) / (H' + z))^{1/4} \times r(L) \qquad \text{--- Formula 1}$$

[0027] Then, the bore is configured such that the radius r(z) thereof at an arbitrary position satisfies the Formula 1, so that a pressure applied onto the bore wall surface is reduced gradually and gently in a downward direction from the upper end of the nozzle (upper end of the bore) to provide a low-energy less, smooth and straightened molten steel flow.

[0028] The above formula for calculating the pressure distribution using the H' is set up on an assumption that molten steel flows into the upper end of the bore directly and uniformly in an approximately vertical direction according to a hydrostatic head pressure of a molten steel bath in the tundish. However, in actual casting operations, multi-directional flows of molten steel are formed from the vicinity of a bottom surface of the tundish adjacent to the upper end of the nozzle serving as an inlet of a molten steel discharge passage, toward the bore, as described above. Thus, to accurately

figure out an actual pressure distribution in the bore, it is necessary to use a hydrostatic head having a large influence on a flow of molten steel from the vicinity of the bottom surface of the tundish adjacent to the upper end of the nozzle, in place of the H'.

[0029] Therefore, the inventers carried out studies based on various simulations. As a result, the inventers found out that it is effective to use a value of the H' to be obtained when zero is assigned to z in the Formula 1, as a hydrostatic head height H for the calculation, i.e., calculational hydrostatic head height H (hereinafter referred to simply as "H", on a case-by-case basis).

[0030] Specifically, the H can be expressed as follows:

$$H = ((r(L) / r(0))^4 \times L) / (1 - (r(L) / r(0))^4)$$

[0031] As above, the H is defined by a ratio between the radius r (0) of the bore at the upper end of the nozzle and the radius r (L) of the bore at the lower end of the nozzle, and the axial length L of the bore. This calculational hydrostatic head height H has an influence on a pressure of molten steel within the bore of the nozzle of the present invention. In other words, a cross-sectional shape of the bore wall surface calculated using the H in place of the H' in the Formula 1 makes it possible to suppress a rapid pressure change which would otherwise occur adjacent to the upper end of the bore.

[0032] When the H in the above formula is converted to a ratio of the r (0) to the r (L), the formula can be transformed into the following formula:

$$r(0) / r(L) = ((H + L) / (H + 0))^{1/4} \qquad \text{--- Formula 2}$$

[0033] The Formula 2 can be transformed as follows:

$$r(0) / r(L) = (1 + L / H)^{1/4}$$

$$L / H = (r(0) / r(L))^4 - 1$$

$$H = L / ((r(0) / r(L))^4 - 1) \qquad \text{--- Formula 3}$$

[0034] The H is indicated in FIG. 9 which is a schematic axial cross-sectional view illustrating a tundish and an upper nozzle, wherein the upper end of the bore is an origin (zero point) of the distance z.

[0035] Through further researches, the inventors have found out that the rapid pressure change which would otherwise occur adjacent to the upper end of the bore can be suppressed by setting the radius r(0) of the upper end of the bore to be 1.5 times or more the radius r(L) of the lower end of the bore. This is because, if the radius r(0) of the upper end of the bore is less than 1.5 times the radius r(L) of the lower end of the bore, it becomes difficult to sufficiently ensure a distance for smoothing a configuration from the tundish or ladle to the upper nozzle, so that the configuration is rapidly changed. Preferably, the radius r(0) of the upper end of the bore is equal to or less than 2.5 times the radius r(L) of the lower end of the bore, because a discharge opening of the tundish or ladle will be unrealistically increased along with an increase in the radius r(0) of the upper end of the bore.

[0036] Further, on an assumption that a molten steel flow smoother than ever before can be formed by using the calculational hydrostatic head height H, in the Formula 1 (i.e., $r(z) = ((H' + L) / (H' + z))^{1/4} \times r(L)$), in place of the hydrostatic head height H' of a molten steel bath, and setting a cross-sectional configuration of the bore wall surface of the upper nozzle according to Formula 4: $r(z) = ((H + L) / (H + z))^{1/n} \times r(L)$) (wherein n may be any integer other than 4), the inventors verified a pressure on a bore wall surface in each of various upper nozzles with bore configurations set by changing a value of the n.

The variable n is applied to the Formula 3 to express the calculational head height H as follows:

$$H = L / ((r(0) / r(L))^n - 1) \qquad \text{--- Formula 5}$$

[0037] Then, the Formula 4 can be expressed as follows by assigning the Formula 5 thereto:

$$r(z) = [\ [L / \{(r(0) / r(L))^n - 1\} + L] / [L / \{(r(0) / r(L))^n - 1\} + z]]^{1/n} \times r(L)\ ]$$

--- Formula 6

In other words, the radius r(z) of the bore at a position downwardly away from the upper end of the bore by an arbitrary distance z is expressed by the Formula 6.
In the Formula 6, r(z) for n = 1.5 corresponds to the curve (line) 15 in FIG. 1 represented by the aforementioned Formula A, and r(z) for n = 6 corresponds to the curve (line) 16 in FIG. 1 represented by the aforementioned Formula B.

[0038] The present invention will be more specifically described based on examples. It is to be understood that that the following examples will be shown simply by way of illustrative embodiments of the present invention, and the present invention is not limited to the examples.

[EXAMPLE 1]

[0039] In an inventive example 1, a distribution of pressures to be applied onto a bore wall surface of an upper nozzle when a hydraulic head height in a tundish or a ladle is 1000 mm was calculated, wherein: a length of the upper nozzle is 230 mm; a diameter of a large-diameter end of a bore of the upper nozzle is 140 mm; a diameter of a small-diameter end of the bore is 70 mm; and a radius r(z) of the bore, i.e., a line indicative of the bore wall surface in a vertical cross-section taken along an axis of the bore, is expressed by $[[L / \{(r(0) / r(L))^n - 1\} + L] / [L / \{(r(0) / r(L))^n - 1\} + z]]^{1/n} \times r(L)\ ]$, where n = 4 (inventive example 1), i.e., $[[L / \{(r(0) / r(L))^4 - 1\} + L] / [L / \{(r(0) / r(L))^4 - 1\} + z]]^{1/4} \times r(L)\ ]$, as indicated by the solid line in FIG. 2(a). FIG. 2(b) illustrates a result of the calculation on an assumption that a pressure to be applied onto a wall surface at an upper end of a bore of an upper nozzle illustrated in FIG. 7 as a conventional upper nozzle is zero. Further, a distribution of pressures to be applied onto a bore wall surface in each of five other types of upper nozzles was calculated and evaluated in the same manner as that in the inventive example 1, wherein: a radius r(z) of a bore in a respective one of the upper nozzles, i.e., a line indicative of the bore wall surface in a vertical cross-section taken along an axis of the bore, is derived from the Formula 6, where n = 1.5 (inventive example 2), n = 2 (inventive example 3), n = 6 (inventive example 4), n = 1 (comparative example 1) or n = 7 (comparative example 2), i.e., expressed by: $[[L/ (r(0) / r(L))^{1.5} - 1\} + L] / [L / \{(r(0) / r(L))^{1.5} - 1\} + z]]^{1.5} \times r(L)\ ]$ (inventive example 2); $[[L / \{(r(0) / r(L))^2 - 1\} + L] / [L / \{(r(0) / r(L))^2 - 1\} + z]]^{1/2} \times r(L)\ ]$ (inventive example 3); $[[L / \{(r(0) / r(L))^6 - 1\} + L] / [L / \{(r(0) / r(L))^6 - 1\} + z]]^{1/6} \times r(L)\ ]$ (inventive example 4)(see FIG. 3(a)); $[[L / \{(r(0) / r(L))^1 - 1\} + L] / [L / \{(r(0) / r(L))^1 - 1\} + z]]^{1/1} \times r(L)\ ]$ (comparative example 1)(see FIG. 4(a)); or $[[L / \{(r(0) / r(L))^7 - 1\} + L] / [L / \{(r(0) / r(L))^7 - 1\} + z]]^{1/7} \times r(L)\ ]$ (comparative example 2) (see FIG. 5(a)). A result of the evaluation is illustrated in Table 1.

[0040] TABLE 1

[0041] In the inventive example 1, it was verified that the pressure is gradually changed from the upper end to the lower end of the bore (see FIG. 2(b)). It is proven that no rapid pressure change occurs, and a molten steel flow is approximately constant or stabilized. In each of the inventive examples 2 (n = 1.5) and 3 (n = 2), it was also verified that the pressure is gradually changed from the upper end to the lower end of the bore, as with the inventive example 1.

[0042] In the inventive example 4 (n = 6), it was verified that, although a large pressure change is observed in an upper end region of the bore, the pressure is subsequently gradually changed (see FIG. 3(b)). It is proven that a molten steel flow is approximately stabilized, except in the upper end region of the bore where the bore is wide and therefore an adhesion matter is less likely to cause a problem.

[0043] In the comparative example 1 (n = 1), it was verified that the pressure change from the upper end to the lower end of the inner bore is small (see FIG. 4(b)). However, as is clear, for example, when comparing between FIG. 2(b) and FIG. 4(b), it was verified that a rapid pressure change occurs just after molten steel flows from the upper nozzle into the upper plate, i.e., the molten steel flow is rapidly changed in an area where the bore is narrow and therefore a n is more likely to cause a problem.
It is considered that this is because the bore wall surface of the upper nozzle has a reverse taper shape, so that a corner is formed in a contact region with the upper plate, and a pressure distribution curve has a very little slope, i.e., a high pressure is maintained even at the lower end of the bore (see FIG. 4(b)).

[0044] In the comparative example 2 (n = 7), the pressure is largely changed from about 100 Ps in the upper end region of the bore, as illustrated in FIG. 5. Specifically, it was verified that a pressure greater than that in the conventional upper nozzle (FIG. 7) occurs in the upper end region of the bore, and subsequently the pressure is extremely largely changed. In the comparative example 2, it is proven that the radius of the bore is sharply reduced in the upper end region of the bore, and the molten steel flow is rapidly changed in an area where the bore is narrow and therefore an adhesion matter is more likely to cause a problem.

[0045] As above, in the present invention, it is proven that a change in pressure to be applied to the bore wall surface is approximately constant during passage of molten steel through the bore of the upper nozzle, i.e., the molten steel

flow is a low-energy loss and stabilized flow. A molten-steel level in a ladle will be gradually lowered from about 4000 mm, and a molten-steel level in some tundishes is about 500 mm. However, as mentioned above, molten metal flowing into the discharge opening is molten metal located adjacent to the bottom surface of the tundish or ladle. Thus, although a value of the pressure is changed due to a change in molten-steel level height, the pressure distribution has the same characteristic as those in the inventive and comparative examples.

[0046] Secondly, the inventors carried out a study on a smooth nozzle in which no corner (bend point) is formed in a bore wall surface thereof, i.e., a nozzle in which a curve in a vertical cross-section of a bore thereof is formed as a curve of continuous differential values of r(z) with respect to z, i.e., (d(r(z))/dz).

Specifically, the inventors carried out a study on an upper nozzle in which a curve in a vertical cross-section of a bore thereof is smooth but it does not conform to that according to the Formula 6, using, as criteria, three points by which the axial length L of the bore is divided into quarters. A smooth bore configuration having no bend point is substantially determined by specifying total five points consisting of the upper and lower ends of the bore and the above three points. Thus, it is considered that, even if two upper nozzles are somewhat different from each other in terms of bore configuration, such a difference is minor as long as they satisfy the criteria, and they exhibit the same tendency regarding the pressure change.

[0047] In the inventive example 5, a distribution of pressures to be applied onto a bore wall surface of an upper nozzle was calculated and evaluated in the same manner as that in the inventive example 1, wherein: a length of the upper nozzle is 230 mm; a diameter of a large-diameter end of a bore of the upper nozzle is 140 mm; a diameter of a small-diameter end of the bore is 70 mm; bore wall surfaces at the three points by which the axial length L of the bore is divided into quarters, approximate respective values derived from the Formula 6 where n = 6, 4 and 1.5; and the bore has no bend point. A result of the evaluation is illustrated in Table 2.

Further, a distribution of pressures to be applied onto a bore wall surface in each of three types of upper nozzles was calculated and evaluated in the same manner as that in the inventive example 1, wherein radii at the three points approximate: respective values derived from the Formula 6, where n = 4, 6 and 4 (inventive example 6); respective values derived from the Formula 6, where n = 2, 4 and 6 (inventive example 7); or respective values derived from the Formula 6, where n = 7, 6 and 4 (comparative example 3). A result of the evaluation is illustrated in Table 2.

[0048] TABLE 2

[0049] In the inventive example 5, it was verified that, although a large pressure change is observed in the upper end region of the bore, the pressure is subsequently gradually changed, as with the inventive example 4. It is proven that a molten steel flow is approximately stabilized, except in the upper end region of the bore where the bore is wide and therefore an adhesion matter is less likely to cause a problem.

[0050] In the inventive examples 6 and 7, it was verified that the pressure is gradually changed from the upper end to the lower end of the bore. It is proven that no rapid pressure change occurs, and a molten steel flow is approximately stabilized.

[0051] In the comparative example 3, it was verified that a large pressure occurs in the upper end region of the bore, and subsequently the pressure is rapidly reduced, as with the comparative example 2. In the comparative example 3, it is proven that the radius of the bore is sharply reduced in the upper end region of the bore, and the molten steel flow is rapidly changed in an area where the bore is narrow and therefore an adhesion matter is more likely to cause a problem.

[0052] As above, it is proven that, even if a bore configuration of an upper nozzle is somewhat deviated from the Formula 6, an excellent flow as compared to the conventional upper nozzle can be created as long as bore wall surfaces at three points by which an axial length L of a bore of the upper nozzle is divided into quarters, approximate respective values derived from the Formula 6 where n = 1.5 to 6, and the bore has no bend point.

[0053] Thirdly, the inventors carried out a study on a relationship between a distribution of pressures to be applied onto a bore wall surface of an upper nozzle, and an inner diameter ratio of an upper end to a lower end of a bore of the upper nozzle.

In the inventive example 8, a distribution of pressures to be applied onto a bore wall surface in each of three types of upper nozzles was calculated and evaluated in the same manner as that in the inventive example 1, wherein: a length of each of the upper nozzles is 230 mm; a diameter of a small-diameter end of a bore in each of the upper nozzles is 70 mm; a diameter of a large-diameter end of the bore is 108 mm which is about 1.5 times the diameter D of the small-diameter end (lower end) of the bore (1.54D), and a radius r(z) of the bore is derived from the Formula 6, where n = 1.5, 4 or 6, i.e., expressed by: $[[L / \{(r(0) / r(L))^{1.5} - 1\} + L] / [L / \{(r(0) / r(L))^{1.5} - 1\} + z]]^{1/1.5} \times r(L)$]; $[[L / \{(r(0) / r(L))^4 - 1\} + L] / [L / \{(r(0) / r(L))^4 - 1\} + z]]^{1/4} \times r(L)]$; or $[[L / \{(r(0) / r(L))^6 - 1\} + L] / [L / \{(r(0) / r(L))^6 - 1\} + z]]^{1/6} \times r(L)]$. A result of the evaluation is illustrated in Table 3. A result of the evaluation is illustrated in Table 3. Further, as one example, the bore configuration and the calculation result for n = 4 are illustrated in FIG. 6.

Further, in three other cases where the diameter of the large-diameter end of the bore is: 140 mm which is 2 times the diameter D of the small-diameter end (lower end) of the bore (2D) (inventive example 9); 280 mm which is 4 times (4D) (inventive example 10); and 73 mm which is about 1 time (1.06D) (comparative example 4), a distribution of pressures to be applied onto a bore wall surface in the upper nozzle was calculated and evaluated, wherein a radius r(z) of the

bore is derived from the Formula 6, where n = 1.5, 4 or 6, as with the inventive example 8. A result of the evaluation is illustrated in Table 3. Further, the bore configuration and the calculation result in the comparative example 4 (n = 4) are illustrated in FIG. 6.

[0054] TABLE 3

[0055] It was verified that, in the comparative example 4 where the bore diameter ratio is about 1 time (1.06D), the pressure change is large in the upper end region of the bore, whereas, in the inventive example 8 where the bore diameter ratio is about 1.5 times (1.54D), the inventive example 9 where the bore diameter ratio is 2 times (2D), and the inventive example 10 where the bore diameter ratio is 4 times (4D), the pressure change is kept approximately constant even in the upper end region of the bore. When the configuration of the bore wall surface is represented by the r(z), the wall surface continuously extending from the tundish or ladle to the upper nozzle becomes smooth. Thus, a rapid pressure change in the upper end region of the bore can be suppressed by setting the diameter of the upper end of the bore to be 1.5 times or more the diameter of the lower end of the bore.

[0056] Further, in view of the pressure changes in the conventional upper nozzle and the comparative examples 1 to 4, the occurrence of a large pressure change is observed due to the present of a corner or a configuration similar to a corner. Thus, a molten steel flow can be stabilized to suppress the occurrence of an adhesion matter by providing a smooth cross-sectional configuration of a bore wall surface having no corner (bend point), i.e., a cross-sectional configuration based on continuous differential values of r(z) with respect to z, i.e., (d(r(z))/dz, wherein the radius r(z) of the bore it is in a rage between $[[L/\{(r(0)/r(L))^{1.5} - 1\} + L] / [L/\{(r(0)/r(L))^{1.5} - 1\} + z]]^{1/1.5} \times r(L)$ and $[[L/\{(r(0)/r(L))^{6} - 1\} + L] / [L/\{(r(0)/r(L))^{6} - 1\} + z]]^{1/6} \times r(L)$.

[0057] A configuration of an upper end region of the bore is likely to be determined by a factor such as a configuration of a stopper. Further, the upper end region of the bore has a relatively large inner diameter, so that it is less likely to be affected by an adhesion matter. On the other hand, a configuration of a lower end region of the bore is likely to be determined in connection with production conditions. For example, in some cases, it has to be formed in a straight bore to allow a core or the like to be inserted thereinto during production. In the present invention, the lower end region of the bore is formed in a configuration close to a straight bore, so that an influence on an anti-adhesion matter effect is small. Therefore, the cross-section of the bore wall surface may be formed in a configuration having no bend point, except the upper end and lower end regions of the bore.

For example, the configuration having no bend point may include a cross-sectional configuration based on continuous differential values of r(z) with respect to z , such as $r(z) = [[L / \{(r(0) / r(L))^{n} - 1\}+ L] / [L/ \{(r(0)/ r(L))^{n} - 1\} + z]]^{1/n} \times r(L)]$. Further, a bubbling mechanism for injecting an inert gas, such as Ar gas, may be used in combination.

Although the above embodiment has been described by taking an upper nozzle as an example, the molten metal discharge nozzle of the present invention is not limited to an upper nozzle, but the present invention may be applied to any other nozzle, such as an open nozzle, to be installed to a vessel, such as a tundish having an approximately constant hydrostatic head height of molten metal.

EXPLANATION OF CODES

[0058]

10: upper nozzle
11: bore
12: large-diameter end
13: small-diameter end
14: bore wall surface
15: bore wall surface for n = 1.5
16: bore wall surface for n = 6

	Comparative Example 1	Inventive Example 2	Inventive Example 3	Inventive Example 1	Inventive Example 4	Comparative Example 2
n	1	1.5.	2	4	6	7
Result	×	O	O	O	O	×
○ : No problematic pressure change × :Occurrence of problematic pressure change						

	Inventive Example 5	Inventive Example 6	Inventive Example 7	Comparative Example 3
r (1/4L)	88mm	95mm	106mm	85mm
	n=6	n=4	n=2	n=7
r (1/2L)	82mm	78mm	82mm	78mm
	n=4	n=6	n=4	n=6
r (3/4L)	80mm	75mm	73mm	75mm
	n=1.5	n=4	n=6	n=4
Result	○	○	○	×
○ : No problematic pressure change × :Occurrence of problematic pressure change				

	Comparative Example 4	Inventive Example 8	Inventive Example 9	Inventive Example 10
r (L)	73mm	108mm	140mm	280mm
r (0)/r (L)	1.06	1.54	2	4
n=1.5	×	O	O	O
n=4	×	O	O	O
n=6	×	O	O	O
○ : No problematic pressure change × : Occurrence of problematic pressure change				

Claims

1. A molten metal discharge nozzle having in an axial direction thereof a bore for allowing passage of molten metal, wherein:

a radius r(0) of an upper end of the bore is 1.5 times or more a radius r(L) of a lower end of the bore;
a line indicative of a wall surface of the bore in a cross-section taken along an axis of the bore has no bend point;
a radius r(1/4L) of the bore at a position downwardly away from the upper end of the bore by a distance of 1/4L (where L is an axial length of the bore) is in a range between

$$[\ [L/\{(r(0)/r(L))^{1.5} - 1\} + L] / [L/\{(r(0)/r(L))^{1.5} - 1\} + 1/4\ L]\ ]^{1/1.5} \times r(L)$$

and

$$[\ [L/\{(r(0)/r(L))^{6} - 1\} + L] / [L/\{(r(0)/r(L))^{6} - 1\} + 1/4\ L]\ ]^{1/6} \times r(L);$$

a radius r(1/2L) of the bore at a position downwardly away from the upper end of the bore by a distance of 1/2L is in a range between

$$[\ [L/\{(r(0)/r(L))^{1.5} - 1\} + L] / [L/\{(r(0)/r(L))^{1.5} - 1\} + 1/2\ L]\ ]^{1/1.5} \times r(L)$$

and

$$[\ [L/\{(r(0)/r(L))^{6} - 1\} + L] / [L/\{(r(0)/r(L))^{6} - 1\} + 1/2\ L]\ ]^{1/6} \times r(L);$$

and

a radius r(3/4L) of the bore at a position downwardly away from the upper end of the bore by a distance of 3/4L is in a range between

$$[\ [L/\{(r(0)/r(L))^{1.5} - 1\} + L] / [L/\{(r(0)/r(L))^{1.5} - 1\} + 3/4\ L]\ ]^{1/1.5} \times r(L)$$

and

$$[\ [L/\{(r(0)/r(L))^{6} - 1\} + L] / [L/\{(r(0)/r(L))^{6} - 1\} + 3/4\ L]\ ]^{1/6} \times r(L).$$

Fig.1

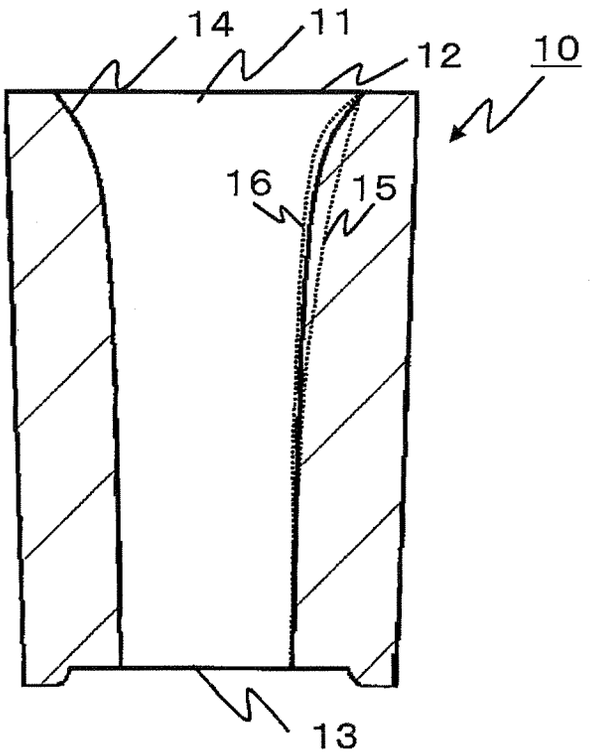
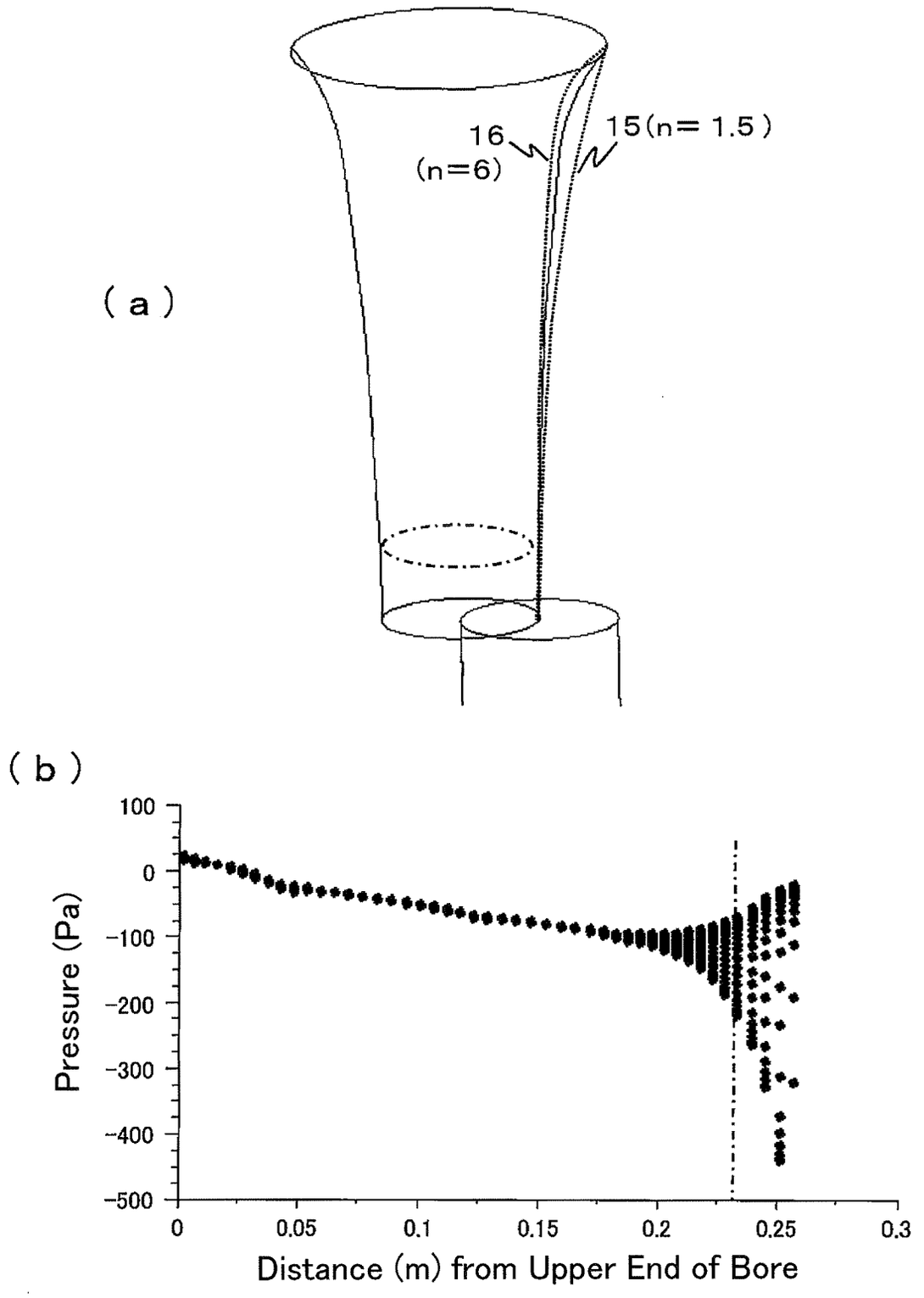


Fig.2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16
(n=6)
15(n= 1.5)
(b)
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0
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-200
-300
-400
-500
Pressure (Pa)
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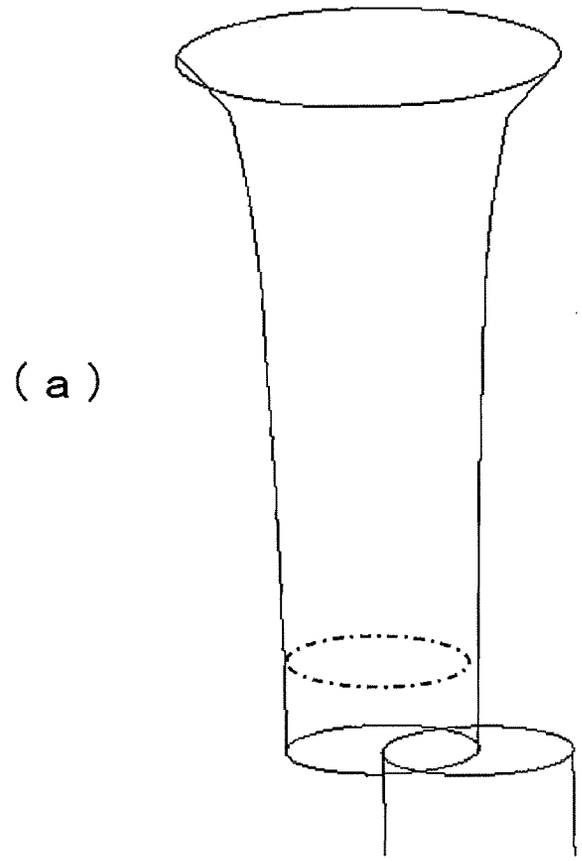
0.05
0.1
0.15
0.2
0.25
0.3
Distance (m) from Upper End of Bore

Fig.3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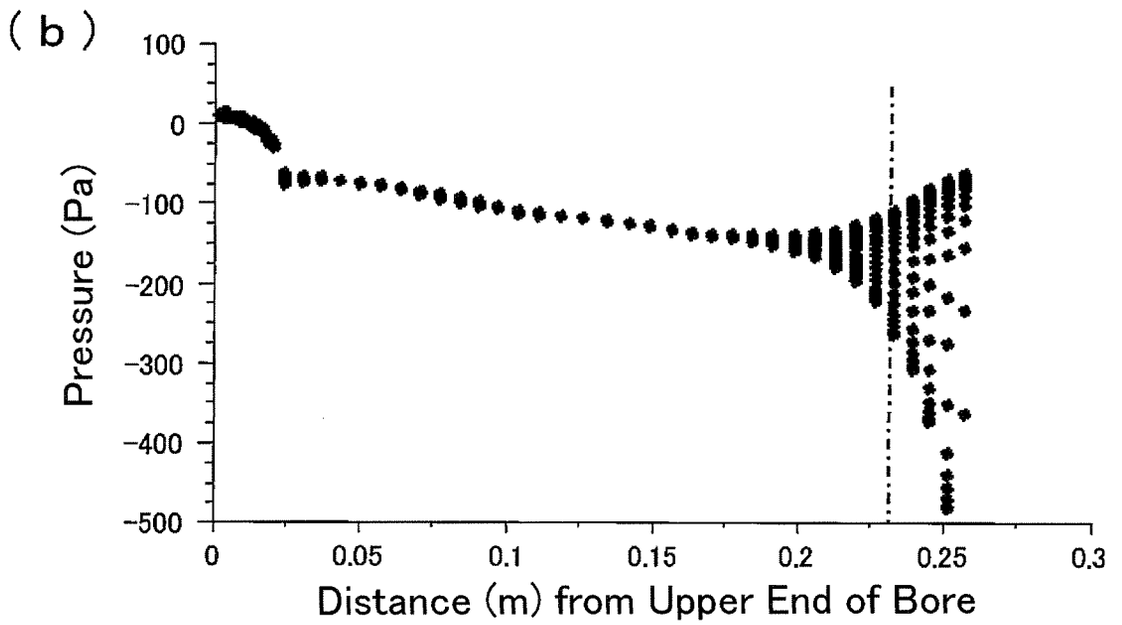
(b)
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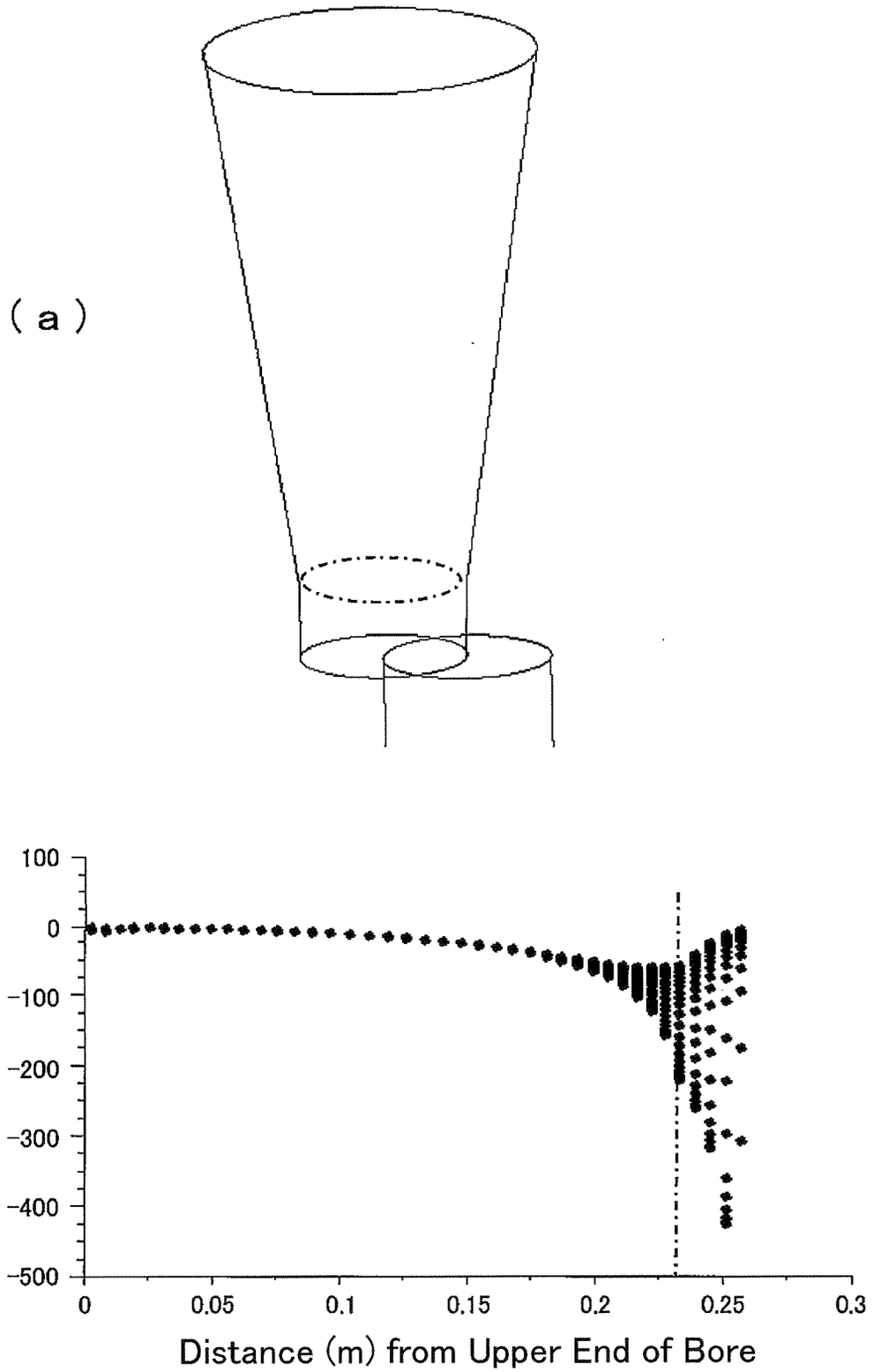
0.2
0.25
0.3
Distance (m) from Upper End of Bore

Fig.4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(b)
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Pressure (Pa)
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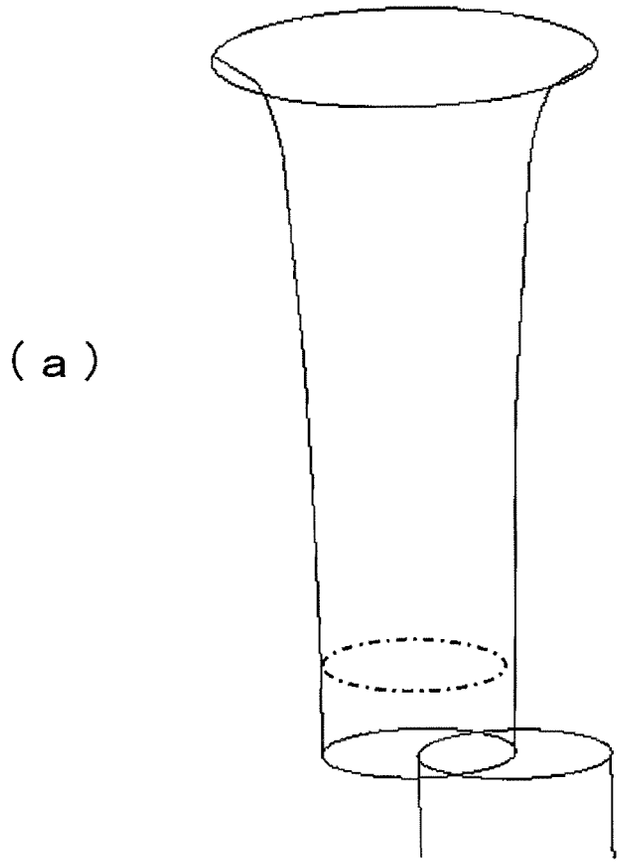
0.2
0.25
0.3
Distance (m) from Upper End of Bore

Fig.5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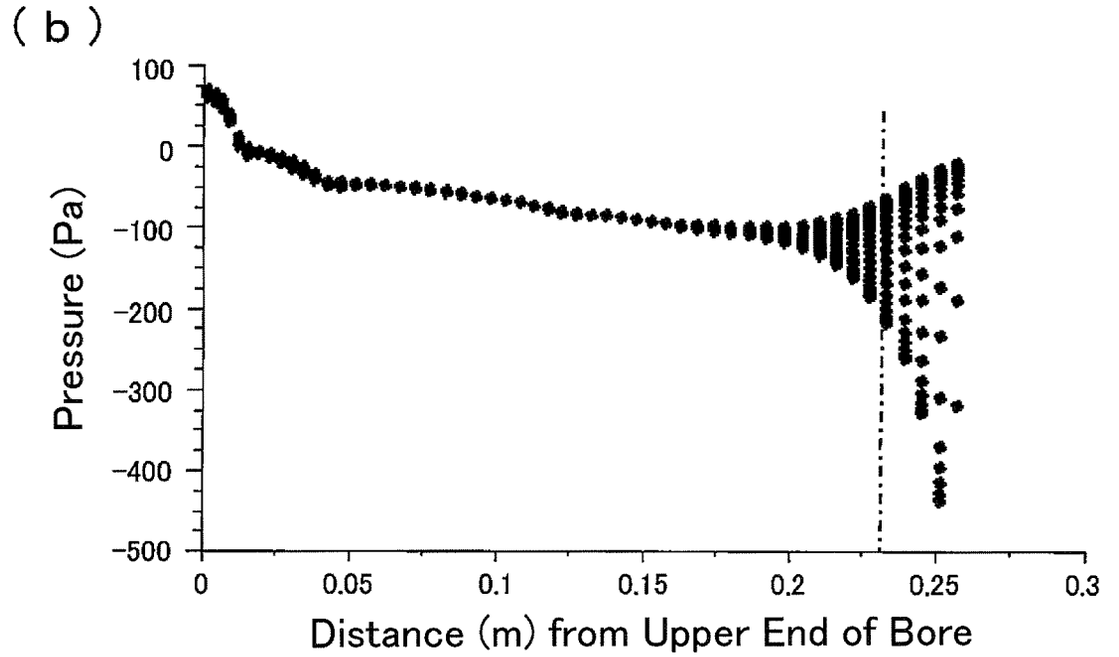
(b)
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0
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−200
−300
−400
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Pressure (Pa)
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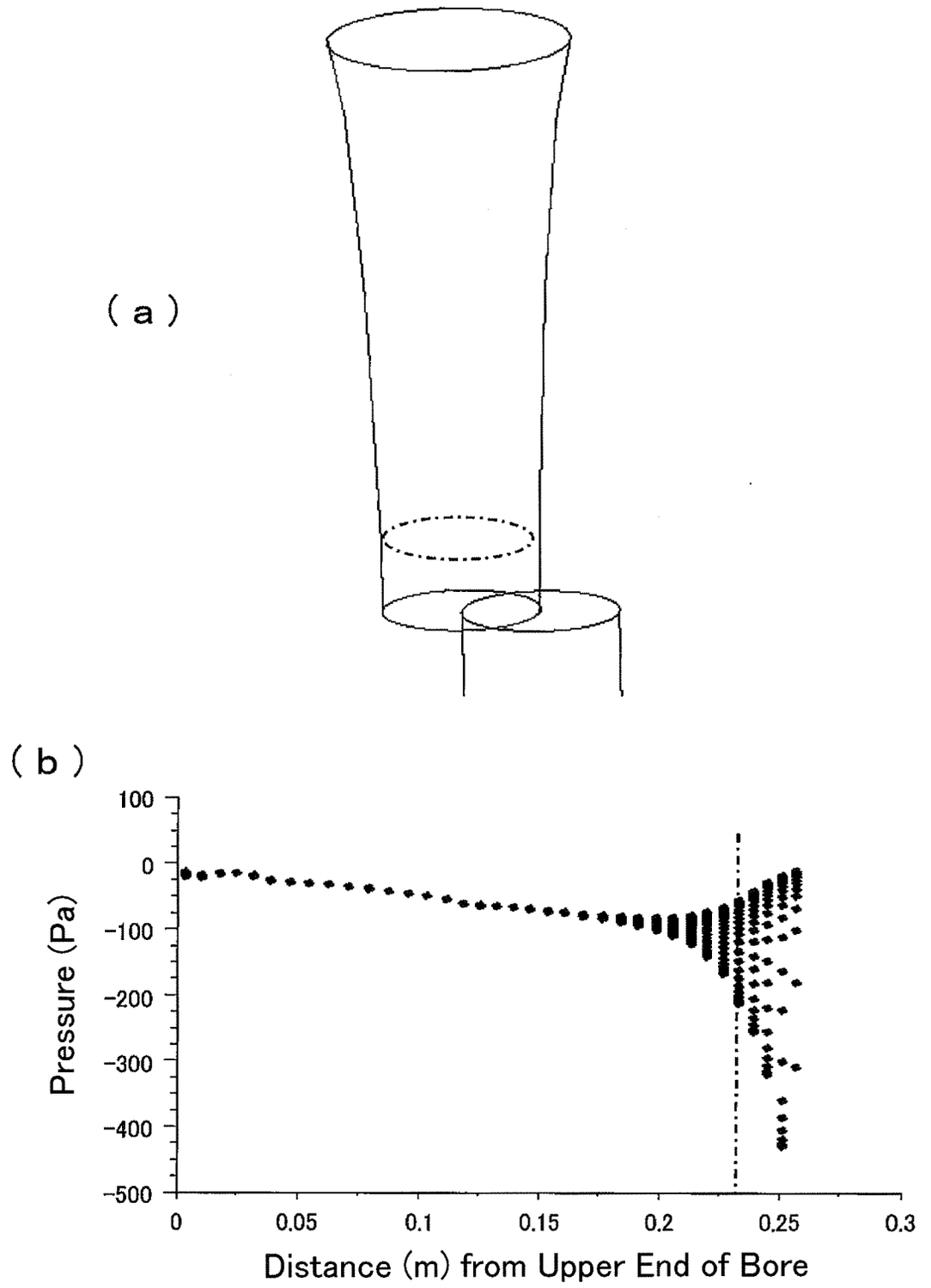
0.05
0.1
0.15
0.2
0.25
0.3
Distance (m) from Upper End of Bore

Fig.6


(a)
(b)
100
0
-100
-200
-300
-400
-500
Pressure (Pa)
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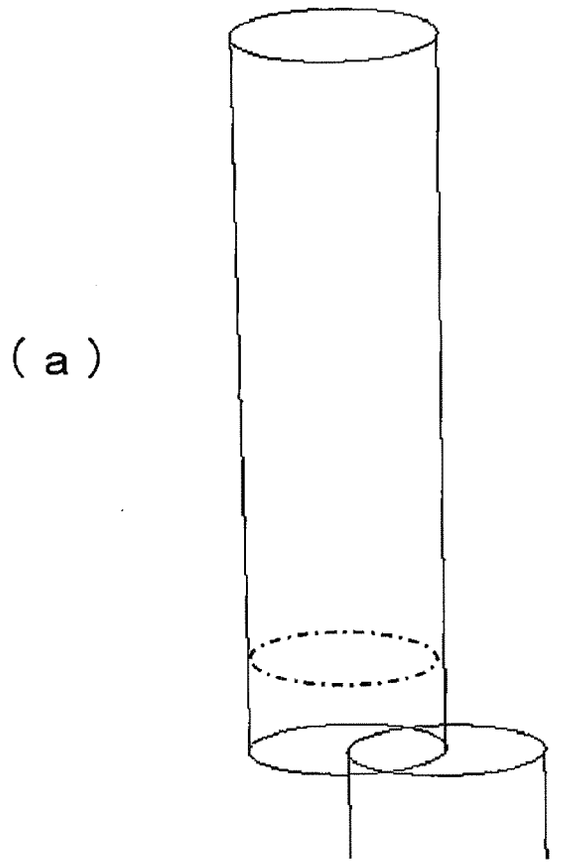
0.05
0.1
0.15
0.2
0.25
0.3
Distance (m) from Upper End of Bore

Fig.7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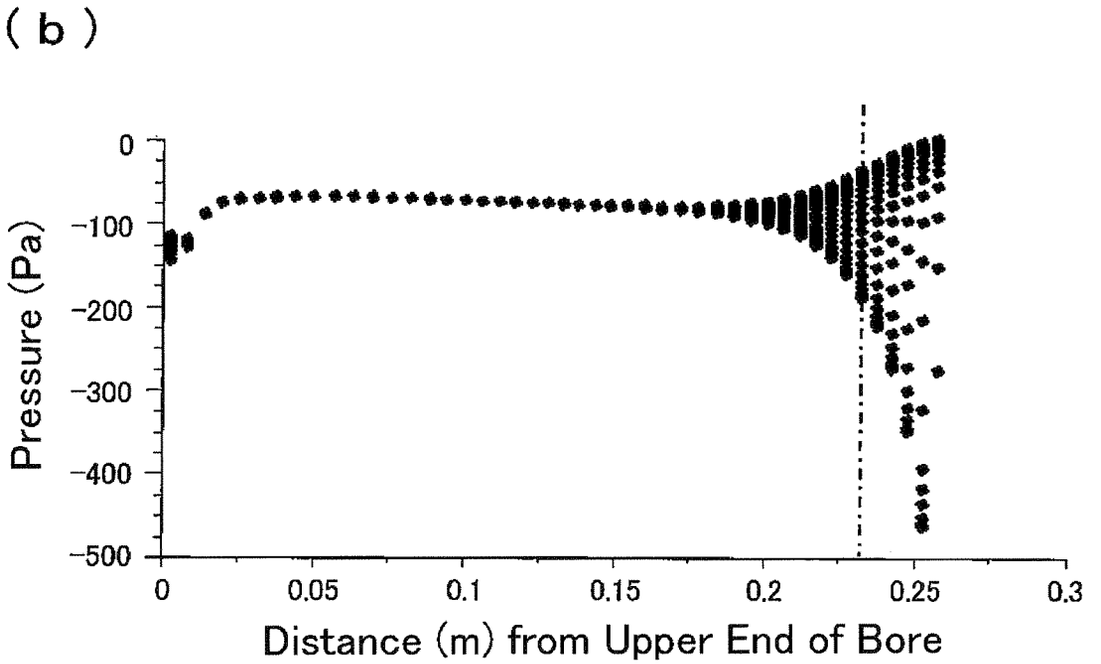
(b)
Pressure (Pa)
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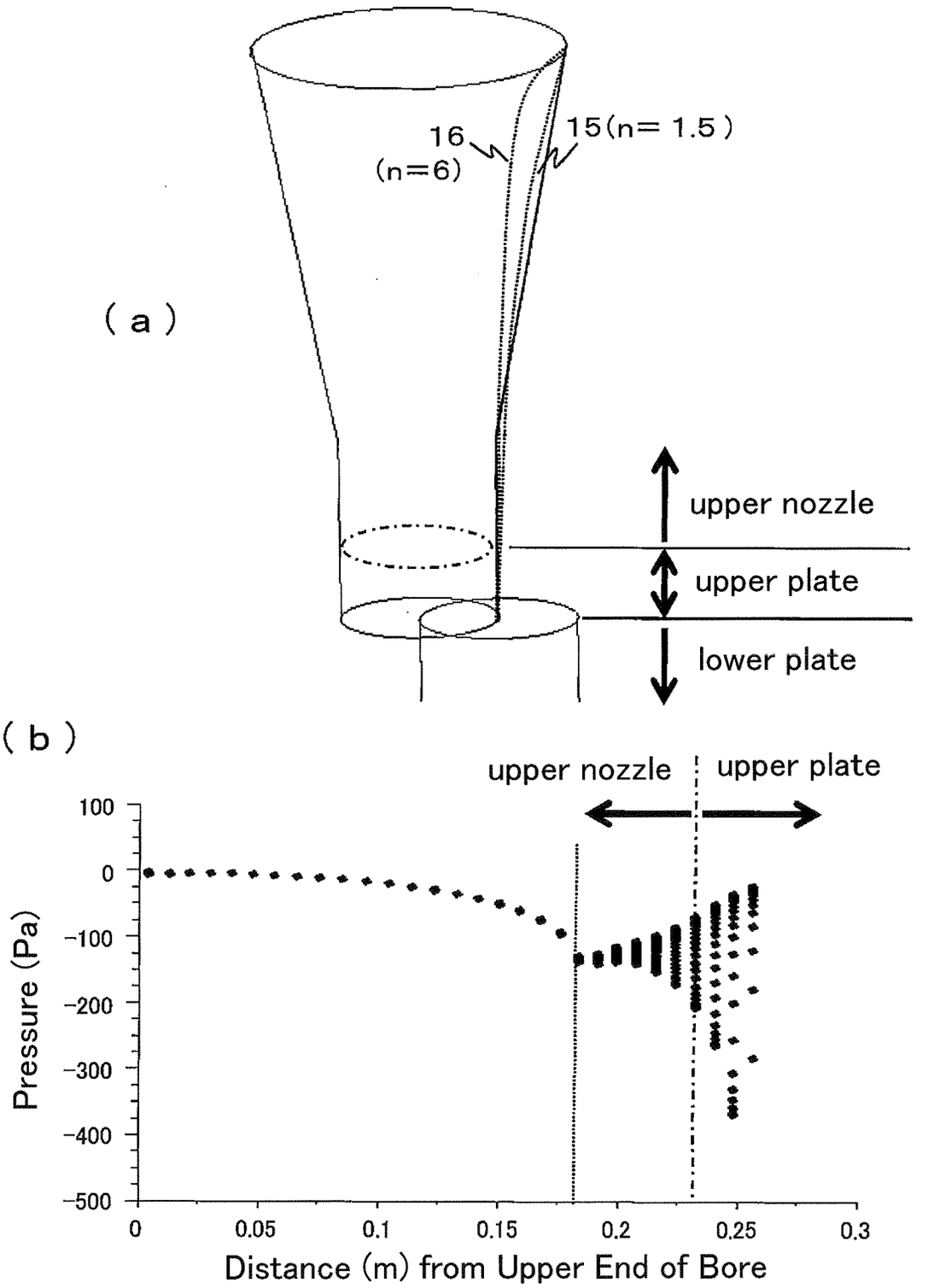
-100
-200
-300
-400
-500
0
0.05
0.1
0.15
0.2
0.25
0.3
Distance (m) from Upper End of Bore

Fig.8


(a)
16
(n=6)
15(n= 1.5)
upper nozzle
upper plate
lower plate
(b)
upper nozzle
upper plate
Pressure (Pa)
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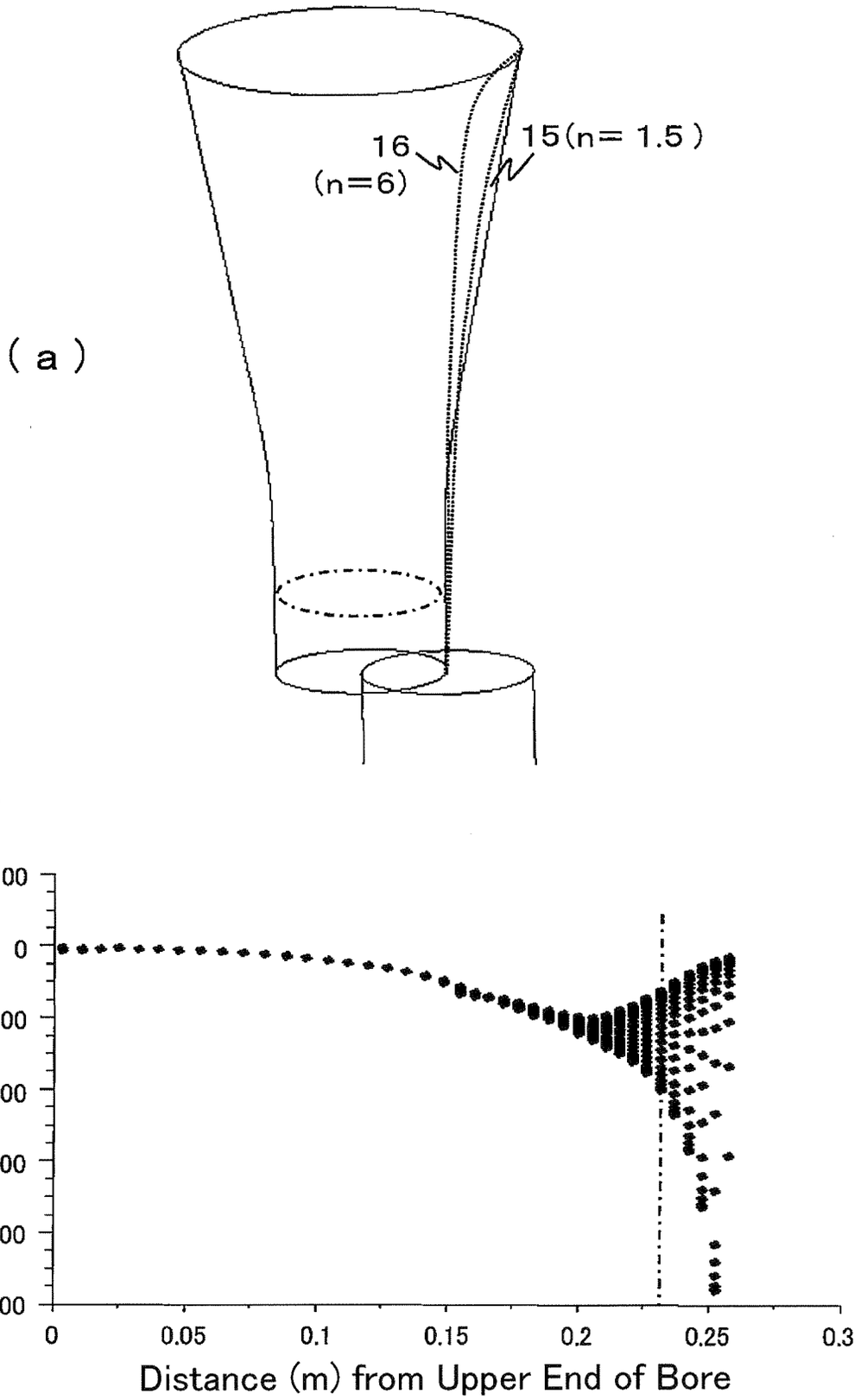
0
-100
-200
-300
-400
-500
0
0.05
0.1
0.15
0.2
0.25
0.3
Distance (m) from Upper End of Bore

Fig.9


(a)
16
(n=6)
15(n= 1.5)
(b)
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0
-100
-200
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-400
-500
Pressure (Pa)
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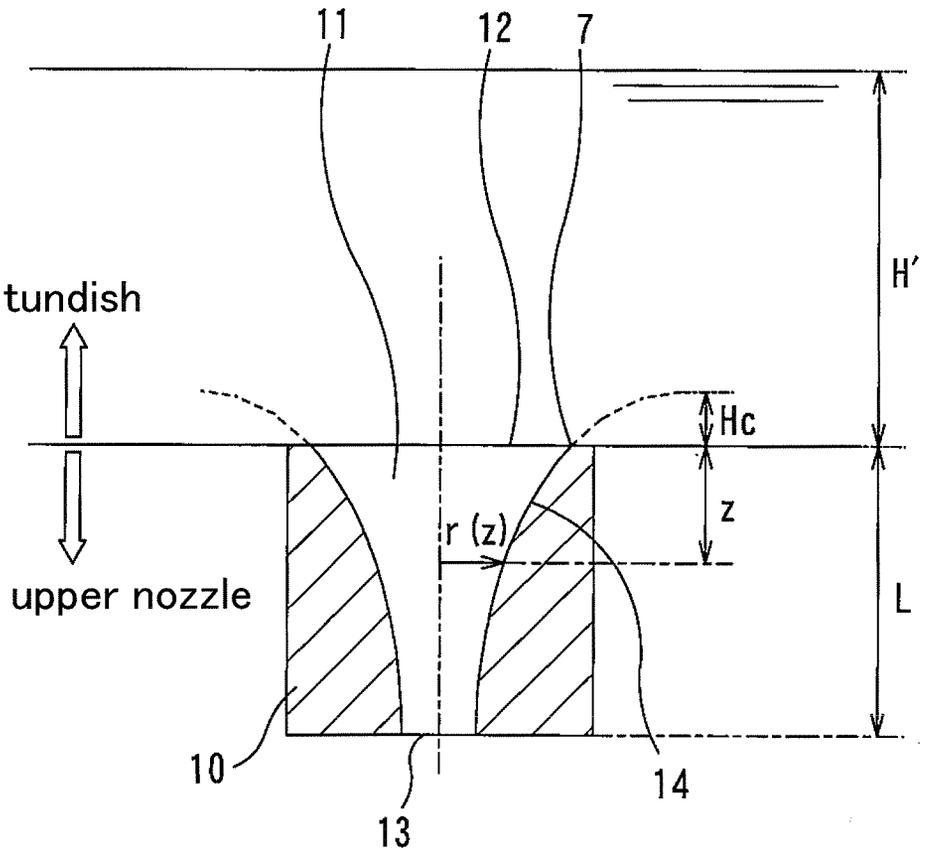
0.05
0.1
0.15
0.2
0.25
0.3
Distance (m) from Upper End of Bore

Fig.10



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2010/059308

A. CLASSIFICATION OF SUBJECT MATTER
B22D41/50(2006.01)i, *B22D11/10*(2006.01)i, *B22D46/00*(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B22D41/50, B22D11/10, B22D46/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2010
Kokai Jitsuyo Shinan Koho 1971-2010 Toroku Jitsuyo Shinan Koho 1994-2010

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 7-16715 A (Nippon Steel Corp.), 20 January 1995 (20.01.1995), entire text (Family: none)	1
A	JP 3639513 B2 (Kurosaki Harima Corp.), 20 April 2005 (20.04.2005), entire text (Family: none)	1

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
03 August, 2010 (03.08.10)	10 August, 2010 (10.08.10)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2010/059308

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CD-ROM of the specification and drawings annexed to the request of Japanese Utility Model Application No. 32759/1993(Laid-open No. 86850/1994) (Nippon Steel Corp.), 20 December 1994 (20.12.1994), entire text (Family: none)	1

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2007090423 A **[0011]**
- JP 2005279729 A **[0011]**
- JP 2008501854 A **[0011]**