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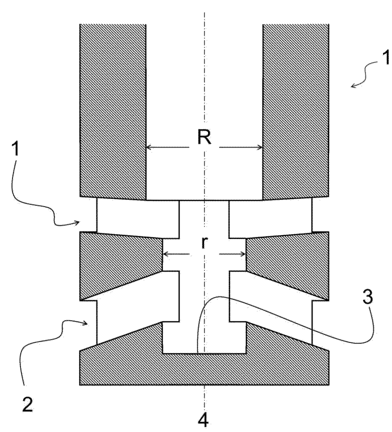
(54) **IMMERSION NOZZLE, MOLD, AND STEEL CONTINUOUS CASTING METHOD**

(57) Provided is a technique of reducing adhesion of inclusion in molten steel to a nozzle and nozzle erosion while properly controlling a flow of molten steel in a mold. Proposed is an immersion nozzle that supplies molten steel from a storage vessel for steel to a mold of a continuous casting machine in continuous casting of steel, in which an end of a main body of the nozzle to be immersed into the molten steel in the mold is closed, a pair of discharge ports having a central axis as a symmetry axis is provided in each of an upper and lower position of the main body of the nozzle to be immersed in the molten steel, and an area of an opening part of the lower discharge port is within 1.0 to 1.6 times, inclusive, of an area of an opening part of the upper discharge port. It is preferable that a ratio r/R of an inner diameter r from the upper end of the upper discharge port to the bottom end of the immersion nozzle to an inner dimeter R up to the upper end of the upper discharge port in a flow path inside the immersion nozzle is 0.6 or more but less than 1.0, and discharge directions of the upper discharge port and the lower discharge port are arranged at an angle θ within 10° in a top plan view.

Fig. 1



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Description

Technical Field

[0001] This invention relates to an immersion nozzle for pouring molten steel into a mold in continuous casting of steel, and a mold for a continuous casting machine, and a continuous casting method of steel using the immersion nozzle.

Background Art

[0002] In continuous casting of steel, molten steel is poured into a mold by immersing an immersion nozzle into the molten steel. The flow of the molten steel discharged through a pair of right and left discharge ports in the immersion nozzle collides with the inner wall of the mold on its short side and diverges into an upward flow rising along the inner wall of the mold and a downward flow descending along the inner wall of the mold.

[0003] In such a case, especially when the discharge flow velocity is high, an uneven distribution of the flow velocity may occur at the top and bottom of the discharge ports. This may cause unbalanced flow speeds between the left and right sides in the upward and downward flows, or a locally strong discharge flow, resulting in a significant fluctuation of the flow. Such a fluctuation causes poor formation of solidification shell or an occurrence of defects resulting from trapping of bubbles or inclusion in a solidified shell.

[0004] In order to solve this problem, a continuous casting method has been studied that can prevent defects due to bubbles or inclusions by slowing down the flow of the molten steel in the mold as well as forming a uniform flow. Based on this insight, a 4-hole type immersion nozzle formed by providing discharge ports for molten steel at two levels, an upper and lower positions, in the vertical direction (4-hole nozzle) is proposed, for example, in Patent Literature below.

[0005] Patent Literature 1 discloses a nozzle having a larger area of an upper discharge port than that of a lower discharge port to reduce a maximum descending flow speed as much as possible, and a continuous casting method using the nozzle.

Citation List

Patent Literature

[0006] Patent Literature 1: WO2010/109887 A1

Summary of Invention

Technical Problem

[0007] Although the technique disclosed in Patent Literature 1 achieves the reduction of the descending flow speed, the molten steel flow to the upper and lower discharge ports is easily biased by a law of gravity, resulting in a high pressure in the bottom of the nozzle. Therefore, the molten steel is stagnated in the bottom of the nozzle to cause the inclusion present in the molten steel to react and adhere to an inner tube of the immersion nozzle or to cause erosion of the inner tube. Further, the sectional area of each discharge port is relatively small as compared to the 2-hole nozzle, so that there is a problem that the flow of the molten steel is disturbed by the adhesion/erosion to easily obstruct the operation.

[0008] The invention is made to solve the above problem and aims to provide a technique of reducing the adhesion of the inclusion in the molten steel to the nozzle or the erosion of the nozzle while properly controlling the flow of the molten steel in the mold.

Solution to Problem

[0009] In order to solve the problem, the inventors studied the pressure distribution inside the nozzle to optimize the opening area ratio of upper and lower discharge ports in a multi-hole immersion nozzle and the flow rate of each discharge port, and as a result, arrived at the invention.

[0010] The immersion nozzle according to the invention for solving the problem is an immersion nozzle for supplying molten steel from a storage container of the molten steel to a mold in a continuous casting machine for continuous casting of steel, in which an end of a main body of the immersion nozzle to be immersed into the molten steel in the mold is closed, a pair of discharge ports having a central axis as a symmetry axis is provided in each of an upper and lower position of the main body of the nozzle to be immersed in the molten steel, and an area of an opening part of the lower discharge port is within 1.0 to 1.6 times, inclusive, of an area of an opening part of the upper discharge port.

[0011] The immersion nozzle according to the invention may have preferable solution means as follows:

a. a ratio r/R of an inner diameter r to another inner diameter R is 0.6 or more but less than 1.0, wherein r represents the inner diameter of the immersion nozzle from an upper end of the upper discharge port to a bottom end of the immersion nozzle, while R represents the inner diameter of the immersion nozzle up to the upper end of the upper discharge port within a flow path in the immersion nozzle; and

b. the discharge directions of the upper discharge port and the lower discharge port are arranged at an angle θ within 10° in a top plan view.

[0012] The mold according to the invention is a mold for a continuous casting machine having any of the above immersion nozzles, in which the mold is configured to have an index K which is represented by the following equation (1) and affects a variation of a molten surface is within a range of 0.09 to 0.14:

$$K^2 = (L^2 + W^2/4) / TP^2 \quad \ldots\ldots (1),$$

wherein L is a distance [m] from a meniscus to the upper end of the upper discharge port of the immersion nozzle, W is a distance [m] between short sides of the mold at the position of the meniscus, and TP is a molten steel passing mass [t/min].

[0013] The mold according to the invention may have preferable solutions to the problem, such as providing an electromagnetic stirring apparatus having a direct current coil and an alternating current coil capable of applying a superposed magnetic field of direct current magnetic field and alternating magnetic field to the molten steel in the mold, outside a long side of the mold positioned above the discharge ports of the immersion nozzle, and providing an electromagnetic braking apparatus having a direct current coil capable of applying a direct current magnetic field to the molten steel in the mold, outside a long side of the mold positioned below the discharge ports of the immersion nozzle.

[0014] Further, a continuous casting method according to the invention is characterized by adjusting the index K of a molten surface variation represented by the above equation (1) within a range of 0.09 to 0.14 in continuous casting of steel using any of the above immersion nozzles.

[0015] In the continuous casting method of steel according to the invention, the followings are preferable solutions to problem:

c. applying a magnetic field obtaining by superposing an alternating magnetic field having a magnetic flux density of 0.03 to 0.1 T on a direct current magnetic field having a magnetic flux density of 0.1 to 0.8 T to the molten steel in the mold positioned above the discharge ports of the immersion nozzle immersed in the molten steel in the mold and applying a direct current magnetic field having a magnetic flux density of 0.1 to 0.8 T to the molten steel in the mold positioned below the discharge ports; and

d. flowing an Ar gas from a tundish upper nozzle while controlling a ratio Q_{Ar} / TP of an Ar gas flow rate Q_{Ar} [NL/min] to a molten steel passing mass TP [t/min] within 2.0 to 5.0 inclusive.

Advantageous Effect of Invention

[0016] According to the immersion nozzle and continuous casting machine of the present invention, steel can be continuously cast without forming a high-pressure portion due to stagnation of a flow at the bottom of an immersion nozzle and without causing a negative pressure in the vicinity of a discharge port, by making the area of a lower discharge port of the immersion nozzle larger than that of an upper discharge port. This can prevent the adhesion of inclusions by reaction with a nozzle refractory or nozzle erosion, and an effect of reducing a risk of inhibiting operation is expected. The immersion nozzle according to the invention is preferably used in continuous casting method of steel.

Brief Description of Drawings

[0017]

[Fig. 1] is a longitudinal sectional view of an immersion nozzle according to an embodiment of the present invention.

[Fig. 2] is a schematic view showing a positional relationship of upper and lower discharge ports of an immersion nozzle according to another embodiment of the present invention in a horizontal sectional view.

[Fig. 3] is a graph showing a relationship between a maximum pressure inside an immersion nozzle and a ratio of a sectional area of an upper discharge port to a sectional area of a lower discharge port.

[Fig. 4] is a graph showing a relationship between a minimum pressure in the vicinity of discharge ports of an immersion nozzle and a ratio of a sectional area of an upper discharge port to a sectional area of a lower discharge port.

[Fig. 5] is a graph showing a relationship between a normalized maximum pressure inside an immersion nozzle and an inner diameter ratio r/R of an immersion nozzle.

[Fig. 6] is a schematic view showing a positional relationship of discharge ports of an immersion nozzle which affects the flotation of Ar bubbles in a mold for a continuous casting machine according to the other embodiment of the present invention.

Description of Embodiments

[0018] An embodiment of the invention will be specifically described below. It should be noted that each drawing is schematic and may be different from reality. Also, the following embodiments illustrate the apparatus or method for embodying the technical idea of the invention, and the configuration thereof is not limited to the following. That is, the technical idea of the present invention can be modified within a technical scope disclosed in the claims.

[Immersion nozzle]

[0019] Fig. 1 is a longitudinal sectional view of a tip shape of a multi-hole immersion nozzle according to an embodiment of the invention. In continuous casting of steel, molten steel is charged by immersing such an immersion nozzle into the molten steel in a mold. In this embodiment, the nozzle is provided with two pairs of upper and lower discharge ports, or 4 ports in total, and is so-called 4-hole immersion nozzle.

[0020] In this embodiment, a sectional area of a lower discharge port 2 is set to 1.0 to 1.6 times a sectional area of an upper discharge port 1. The reason for this is described below.

[0021] When using a multi-hole immersion nozzle with upper and lower discharge ports, the focus is typically on how to obtain a reducing effect on the discharge flow rate in order to reduce defects in a cast slab.

[0022] However, the inventors have obtained the following knowledge: The flow of molten steel tends to be biased downward due to gravity. Consequently, the pressure at the bottom 3 of the inner tube in the immersion nozzle increases, often resulting in the formation of a stagnant region. Additionally, negative pressure occurs near the discharge port. These two factors contribute to the reaction between the inclusion in the molten steel and the refractory of the immersion nozzle. As a result, inclusions may adhere to the immersion nozzle or cause erosion of the refractory, making stable operation difficult.

[0023] In an immersion nozzle having an upper discharge port 1 and a lower discharge port 2, an opening area of the lower discharge port 2 is made larger than that of the upper discharge port 1, whereby the flow between the upper and lower discharge ports is rectified to reduce a retention portion, or stagnant portion formed in the bottom 3 of the immersion nozzle. The size of the stagnant portion causes the change of the area balance between the upper and lower discharge ports and the inner diameter of the nozzle main body in the vicinity of the discharge ports, which is a factor determining the flow of the molten steel, and such a factor exerts on the "continuity" of the flow field of the molten steel, so that it is difficult to predict the influence by such a factor.

[0024] In order to control the formation of the stagnant portion resulting from the local high pressure portion or negative pressure portion using the size balance between the upper and lower discharge ports, the influence of the area ratio between the upper and lower discharge ports on the stagnant portion is evaluated by numerical calculation.

[0025] The inventors also considered that the stagnant portion in the bottom of the nozzle can be controlled by directing a part of the molten steel flow to collide with the refractory disposed between the upper and lower discharge ports and thereby forcibly directing the part of the molten steel flow to the upper discharge port, and consequently examined the influence of the change in the inner diameter of the nozzle main body in the vicinity of the discharge port on the stagnant portion by numerical calculation.

[0026] As shown in Fig. 2, the positions of the upper and lower discharge ports 1, 2 are preferably shifted by up to a maximum of 10°, as an angle difference θ (°) in a circumferential direction of the nozzle. The lower discharge port 2 is preferably arranged opposite to a short side of the mold in such a manner that the discharge direction of the molten steel is parallel to a long side of the mold and the upper discharge port 1 is preferably shifted in the circumferential direction. That is because, even if the adhesion of alumina or the like is caused in the nozzle, the flow from the upper discharge port 1 is directed to collide with the long side of the mold, which can be expected to suppress the influence of the molten steel flow directly impinging on the molten surface. Thus, the influence on the molten surface level can be suppressed. On the other hand, if the shift angle is too large, the molten steel flow may be deflected due to the collision of the molten steel flow with the long side face of the mold, which may increase the molten surface variation by upward flow. The angle difference θ is preferably more than 1° but not more than 10°, more preferably more than 3° but less than 10°.

<Analysis 1>

[0027] First, 4-hole immersion nozzles No. 1 to No. 5 were subjected to numerical calculation. Note that each nozzle has a straight shape with an inner diameter R of 150 mm and is provided with upper discharge ports and lower discharge ports with an opening shape as shown in Table 1. In the analysis evaluation, a general-purpose thermal-fluid analysis solution STAR-CCM+ was used, and the total pressure distribution at a steady state was determined under the conditions that a pressure near the outlet side of the discharge port was 0 and a maximum flow rate in the nozzle was 3.0 m/s. In Table 1, "longitudinal" represents a vertical direction, and "lateral" represents a horizontal direction.

Table 1

No.	Upper discharge port		Lower discharge port		Area ratio SL/SU	Maximum pressure	Minimum pressure near discharge port
	longitudinal	lateral	longitudinal	lateral			
	mm	mm	mm	mm	-	kPa	kPa
1	45	90	26	90	0.578	40	12
2	45	90	45	90	1.000	27	10
3	45	90	53	90	1.178	20	9
4	45	90	71	90	1.578	18	2
5	45	90	82	90	1.822	17	- 3

[0028] Among the analytical results of Table 1, the relationship between a maximum pressure inside the immersion nozzle and a ratio SL/SU of the sectional area of the upper discharge port 1 to the sectional area of the lower discharge port 2 is shown in the graph in Fig. 3, where SU is the sectional area of the upper discharge port 1 and SL is the sectional area of the lower discharge port 2. As shown in Fig. 3, the maximum pressure decreases as SL/SU increases, i.e., as the sectional area of the lower discharge port 2 becomes larger than the sectional area of the upper discharge port 1, which is considered to eliminate the stagnant portion due to the high pressure. In particular, a large pressure-reduction effect can be obtained when SL/SU is 1.0 or more.

[0029] Further, among analytical results of Table 1, a relationship between a minimum pressure near the discharge port and a ratio SL/SU of the sectional area of the upper discharge port 1to the sectional area of the lower discharge port 2 is shown in the graph of Fig. 4. As shown in Fig. 4, the minimum pressure near the discharge port decreases as SL/SU increases, and particularly becomes negative pressure when SL/SU exceeds 1.6. The inclusion in the molten steel tends to accumulate in the negative pressure portion, which is considered to induce the reaction between the inclusion in the molten steel and the refractory of the immersion nozzle, causing the inclusion to adhere to the immersion nozzle or the refractory in the nozzle to be eroded, similarly in the stagnant portion. Therefore, SL/SU should be set to 1.6 or less.

<Analysis 2>

[0030] Another analysis was performed on an immersion nozzle with SL/SU of 1.0, specifically, on the relationship between a ratio r/R of an inner diameter r from the upper end of the upper discharge port to the bottom end of the immersion nozzle with respect to an inner diameter R up to the upper end of the upper discharge port of the immersion nozzle and the maximum pressure in the flow path inside the nozzle. Table 2 shows the results of the analysis. Note that the maximum pressure inside the nozzle is normalized to be 1.0 when r/R is 1.0. The relationship between the normalized maximum pressure and the inner diameter ratio r/R is shown in the graph of Fig. 5.

Table 2

No.	Area ratio SL/SU	Inner diameter ratio r/R	Normalized maximum pressure
	-	-	-
6	1.000	0.50	1.10
7	1.000	0.60	0.80
8	1.000	0.70	0.67
9	1.000	0.80	0.73
10	1.000	0.95	0.90
2	1.000	1.00	1.00

[0031] As seen from Table 2 and Fig. 5, the inner diameter ratio r/R has an optimum range. The normalized maximum pressure exhibits the lowest value when the inner diameter ratio is about 0.7 and continues to increase whichever the inner diameter ratio increases or decreases. In particular, when r/R is 0.5, the normalized maximum pressure exceeds 1.0. It is considered that the proportion of the area where the refractory disposed between the upper and lower discharge ports collides with the molten steel flow increases, forming a new risk area for the formation of a new high-pressure portion and a new stagnant portion. Therefore, the inner diameter ratio r/R is preferably 0.6 or more but less than 1.0. The normalized maximum pressure can be suppressed to less than 1.0. Preferably, r/R is 0.9 or less.

[0032] An actual continuous casting of steel using an immersion nozzle can be performed by mixing an inert gas such as an Ar gas into molten steel through the tundish upper nozzle. This causes the molten steel to be subjected to buoyancy effect of the bubbles, and the formation of the high-pressure area at the bottom 3 of the immersion nozzle can be alleviated.

[0033] However, if an excessive amount of the inert gas is mixed, the floatability of the flow discharged through the immersion nozzle will be increased in the meniscus inside the steel casting mold, causing the large molten surface variation, which hinders the operation. Therefore, the amount of the gas to be blown should be properly adjusted.

[Mold]

[0034] In a continuous casting method using the above immersion nozzle, an Ar gas or the like may be blown into the nozzle to suppress clogging of the nozzle caused by adhesion of alumina or the like. In particular, bubbles blown out of the upper discharge port 1 together with the molten steel may float up and cause the molten surface to vary. Fig. 6 is an enlarged partial sectional view of a mold 20 for a continuous casting machine, wherein the floating trajectory of bubbles is shown by an arrow attached with a symbol of Ar. Also, the rising position of the bubbles is relevant to a diagonal length $\sqrt{(L^2 + W^2/4)}$ from the upper discharge port 1 to a meniscus position at the short side of the mold, and a molten steel passing mass per unit time TP. According to the inventors' studies, it has been found that the molten surface variation is remarkably suppressed by controlling an index K which affects the molten surface variation within a range of 0.09 to 0.14. Note that the index L is defined by the following equation (1):

$$K^2 = (L^2 + W^2/4) / TP^2 \qquad (1),$$

wherein L is a distance [m] from the meniscus 5 to an upper end of the upper discharge port of the immersion nozzle, W is a distance [m] between the short sides 8 of the mold at a position of the meniscus 5, and TP is a molten steel pass mass per unit time [t/min]. In order to satisfy the equation (1), it is preferable to control the variation of the distance between short sides 8 of the mold, the casting speed acting on the molten steel passing mass, i.e., the pulling speed of cast slab, the immersion depth of the immersion nozzle 10 and so on. Since the distance between the short sides 8 of the mold is fixed at a required width of the mold, it is preferable to adjust the immersion depth of the immersion nozzle 10 or the casting speed.

Examples

Example 1

[0035] The possibility of actual execution and the effect of the invention configured as described above will be described with reference to the following examples.

[0036] Casting was conducted in a vertical bending type continuous casting machine using the nozzle according to the invention, specifically a nozzle and a casting method described in Table 3. As an indicator of operation stability in Table 3, an eddy current sensor was installed just above a molten surface at a central position of the thickness biased from the short side in the widthwise central direction only by 1/4 of the distance W between the short sides of the mold (casting width). The time-varying change of the molten surface level was measured by the eddy current sensor. In this case, the degree of the molten surface level variation in each treatment was represented by an index when the degree of the molten surface level variation in the treatment No. A1 is 100. An average value between the first half and the last half of the casting was used in the evaluation as an index of the operation stability. Note that all the upper and lower discharge ports were opened in a direction opposite to the short side of the mold and the center of the discharge flow was parallel to the long side of the mold.

Table 3

Treatment No.	Area Ratio SL/SU	Inner diameter ratio r/R	Q_{Ar}/TP	Index of molten surface level variation			Remarks
				First half of casting	Latter half of casting	Average	
	-	-	NL/t	-	-	-	
A1	1.178	1.00	1.50	100	100	100	Invention Example
A2	1.178	0.70	1.50	110	63	86.5	Invention Example
A3	1.178	1.00	3.10	120	45	82.5	Invention Example
A4	1.178	0.70	3.10	100	32	66	Invention Example
B1	0.400	0.70	3.10	150	210	180	Comparative Example
B2	0.100	1.00	2.00	180	320	250	Comparative Example

[0037] Table 3 shows that all Invention Examples demonstrate good results as compared to Comparative Examples. When comparing treatments with the same ratio Q_{Ar}/TP regarding the Ar gas flow blown in from the tundish upper nozzle, the treatments Nos. A2 and A4, each with the inner diameter ratio r/R of a suitable range, show better results than the treatments Nos. A1 and A3, each with the inner diameter ratio r/R of 1.0. When comparing treatments with the same inner diameter ratio r/R, the treatments Nos. A3 and A4, each with the ratio Q_{Ar}/TP regarding the Ar gas flow blown in from the tundish upper nozzle in an appropriate range, show better results than the treatments Nos. A1 and A2. In particular, the treatment No. A4 shows the lowest average value of the index of the molten surface level variation and develops a high operation stability.

Example 2

[0038] Table 4 shows the index of the molten surface level variation when a treatment was conducted under the conditions of the treatment No. A1 of Example 1, in which the upper discharge port of the immersion nozzle was shifted by an angle θ with respect to the short side of the mold in the circumferential direction of the nozzle. In the treatments Nos. C2 to C4, in which the angle θ was 3 to 10°, the improvement of the molten surface variation was observed as compared to the treatment No. A1. The treatment No. C5 resulted in a slight increase in the molten surface variation. This is considered due to the fact that the influence of reverse flow, which collided with the long side to reach the molten surface, was increased by excessively shifting the discharge port to the long side.

Table 4

Treatment No.	θ	Index of molten surface level variation			Remarks
		First half of casting	Latter half of casting	Average	
	°	-	-	-	
C1	1	99	101	100	Invention Example
C2	3	90	94	92	Invention Example
C3	7	83	85	84	Invention Example
C4	10	91	89	90	Invention Example
C5	15	130	140	135	Invention Example

Example 3

[0039] Table 5 shows the index of the molten surface level variation when a treatment was conducted under the conditions of the treatment No. A4 of Example 1 by shifting the upper discharge port of the immersion nozzle by 7° with respect to the short side of the mold in the circumferential direction of the nozzle. In the treatment No. D 1, the improvement of the molten surface variation is observed as compared to the treatment No. A4.

Table 5

Treatment No.	θ	Index of molten surface level variation			Remarks
		First half of casting	Latter half of casting	Average	
	°	-	-	-	
D1	7	62	42	56	Invention Example

Example 4

[0040] Table 6 shows an index of the molten surface level variation when the treatment was conducted in the continuous casting machine of Example 1 using the immersion nozzle with a different opening area ratio SL/SU of the upper and lower discharge ports, with a K value of the equation (1) varied . Note that the inner diameter ratio r/R of the immersion nozzle was set 1.00 and the ratio Q_{Ar}/TP regarding the Ar gas blown in from the tundish upper nozzle was set to 1.50. When the K value fell within the range of 0.09 to 0.14, the molten surface variation remarkably increased. Meanwhile, when the K value was too small, the effect of suppressing the molten surface variation was small due to the influence of excessive molten steel passing mass, too narrow casting width, or too shallow immersion depth of the nozzle. Also, when the K value was too large, the effect of suppressing the molten surface variation was small due to the influence of too small molten steel passing mass, too wide casting width, or too deep immersion depth of the nozzle. The inventors believe that it is effective to suppress the molten surface variation keeping a proper distance for reducing the flow speed of the molten steel discharged through the immersion nozzle.

Table 6

Treatment No	Area ratio SL/SU (-)	K value	Index of molten surface level variation (average)	Remarks
E01	0.578	0.05	320	Comparative Example
E02	0.578	0.08	300	Comparative Example
E03	0.578	0.09	296	Comparative Example
E04	0.578	0.12	280	Comparative Example
E05	0.578	0.14	286	Comparative Example
E06	0.578	0.15	295	Comparative Example
E07	0.578	0.17	310	Comparative Example
E08	1.000	0.05	97	Invention Example
E09	1.000	0.08	88	Invention Example
E10	1.000	0.09	64	Invention Example
E11	1.000	0.12	48	Invention Example
E12	1.000	0.14	78	Invention Example
E13	1.000	0.15	83	Invention Example
E14	1.000	0.17	99	Invention Example
E15	1.178	0.05	100	Invention Example
E16	1.178	0.08	95	Invention Example
E17	1.178	0.09	78	Invention Example
E18	1.178	0.12	75	Invention Example
E19	1.178	0.14	79	Invention Example
E20	1.178	0.15	82	Invention Example
E21	1.178	0.17	100	Invention Example
E22	1.578	0.05	103	Invention Example
E23	1.578	0.08	103	Invention Example

(continued)

Treatment No	Area ratio SL/SU (-)	K value	Index of molten surface level variation (average)	Remarks
E24	1.578	0.09	79	Invention Example
E25	1.578	0.12	72	Invention Example
E26	1.578	0.14	79	Invention Example
E27	1.578	0.15	102	Invention Example
E28	1.578	0.17	101	Invention Example
E29	1.822	0.05	300	Comparative Example
E30	1.822	0.08	282	Comparative Example
E31	1.822	0.09	275	Comparative Example
E32	1.822	0.12	268	Comparative Example
E33	1.822	0.14	272	Comparative Example
E34	1.822	0.15	276	Comparative Example
E35	1.822	0.17	298	Comparative Example

Example 5

[0041] An electromagnetic stirring apparatus and an electromagnetic braking apparatus were installed at an upper part and at a lower part, respectively, in the mold in the continuous casting machine of Example 1 as shown in Fig. 6. An alternating current magnetic field was applied to the electromagnetic stirring apparatus at the upper part, by superposing on a direct current magnetic field, while the direct current magnetic field was applied to the electromagnetic braking apparatus at the lower part. Note that the inner diameter ratio r/R of the immersion nozzle was set to 1.00 and the ratio Q_{Ar}/TP regarding the Ar gas blown in through the tundish upper nozzle was set to 1.50. The treatment No. FO1 was equivalent to the treatment No. E11 in Example 4. Each treatment condition and index of the molten surface level variation are shown in Table 7. In the treatments No. F02 to F10, the index of the molten surface level variation was reduced due to the application of the magnetic field as compared to the case without the application of the magnetic field. The treatment No. F02, in which the direct current magnetic field in the lower part was too weak and the direct current magnetic field in the upper part was too strong, gave better results than the cases, in which the alternating current magnetic field in the upper part was too weak and thus no magnetic field was applied. However, the variation of the molten surface variation was promoted. The treatment No. F10, in which the direct current magnetic field in the lower part was too weak and the direct current magnetic field in the upper part was too strong, gave better results than the cases, in which the alternating current magnetic field in the upper part was too strong and thus no magnetic field was applied. However, the variation of the molten steel surface was promoted. The treatment No. F11, in which a magnetic field was applied, had an area ratio SL/SU of the upper and lower discharge ports outside the range defined in the invention, so that the index of the molten surface level variation was deteriorated. Therefore, it is preferable to apply a direct current magnetic field having a magnetic flux density of 0.1 to 0.8 T in the electromagnetic braking apparatus at the lower part. Meanwhile, it is preferable to apply a magnetic field obtained by superposing an alternating current magnetic field having a magnetic flux density of 0.03 to 0.1 T onto a direct current magnetic field having a magnetic flux density of 0.1 to 0.8 T in the electromagnetic stirring apparatus at the upper part. It has been found that the molten surface variation can be further improved by properly combining the electromagnetic stirring with the electromagnetic braking.

Table 7

Treatment No	Area ratio SL/SU	K value	Magnetic field intensity			Index of molten surface level variation (average)	Remarks
			Direct current in lower part	Direct current in upper part	Alternate current in upper part		
	-		T	T	T		
F01	1.000	0.12	0	0	0	48	Invention Example
F02	1.000	0.12	0.05	0.90	0.02	38	Invention Example

(continued)

Treatment No	Area ratio SL/SU	K value	Magnetic field intensity			Index of molten surface level variation (average)	Remarks
			Direct current in lower part	Direct current in upper part	Alternate current in upper part		
	-		T	T	T		
F03	1.000	0.12	0.50	0.50	0.08	18	Invention Example
F04	1.000	0.12	0.15	0.16	0.04	25	Invention Example
F05	1.000	0.12	0.75	0.78	0.04	28	Invention Example
F06	1.000	0.12	0.50	0.50	0.04	32	Invention Example
F07	1.000	0.12	0.15	0.16	0.10	28	Invention Example
F08	1.000	0.12	0.75	0.78	0.10	25	Invention Example
F09	1.000	0.12	0.50	0.50	0.10	30	Invention Example
F10	1.000	0.12	0.05	0.90	0.20	35	Invention Example
F11	0.578	0.12	0.50	0.50	0.08	190	Comparative Example

[0042] In this description, "L" as a unit of volume means 10^{-3} m^3, and "t" as a unit of mass means metric ton = 10^3 kg, and "N" as a symbol representing a volume of a gas means a volume at a standard state that a temperature is 0°C and a pressure is 101325 Pa.

Reference Signs List

[0043]

1 upper discharge port
2 lower discharge port
3 bottom
4 center axis
5 molten surface (meniscus)
6 electromagnetic stirring apparatus
7 electromagnetic braking apparatus
8 short side of mold
10 immersion nozzle
20 mold (for continuous casting machine)
R inner diameter up to upper end of upper discharge port
r inner diameter from upper end of upper discharge port to bottom end of immersion nozzle
W distance between short sides of mold at meniscus position
L distance from meniscus to upper end of upper discharge port of immersion nozzle

Claims

1. An immersion nozzle for supplying molten steel from a storage container of the molten steel to a mold in a continuous casting machine for continuous casting of steel,
characterized in that

an end of a main body of the immersion nozzle to be immersed into the molten steel in the mold is closed,
a pair of discharge ports having a central axis as a symmetry axis is provided in each of an upper and lower position of the main body of the nozzle to be immersed in the molten steel, and
an area of an opening part of the lower discharge port is within 1.0 to 1.6 times, inclusive, of an area of an opening part of the upper discharge port.

2. The immersion nozzle according to claim 1, wherein
a ratio r/R of an inner diameter r to another inner diameter R is 0.6 or more but less than 1.0, wherein r represents the inner diameter of the immersion nozzle from an upper end of the upper discharge port to an bottom end of the immersion nozzle, while R represents the inner diameter of the immersion nozzle up to the upper end of the upper discharge port within a flow path in the immersion nozzle.

3. The immersion nozzle according to claim 1 or 2, wherein
discharge directions of the upper discharge port and the lower discharge port are arranged at an angle θ within 10° in a top plan view.

4. A mold for a continuous casting machine having the immersion nozzle according to any one of claims 1 to 3, wherein

the mold is configured to have an index K which is represented by the following equation (1) and affects a variation of a molten surface is within a range of 0.09 to 0.14:

$$K^2 = (L^2 + W^2/4) / TP^2 \quad \ldots\ldots (1),$$

wherein L is a distance [m] from a meniscus to the upper end of the upper discharge port of the immersion nozzle, W is a distance [m] between short sides of the mold at the position of the meniscus, and TP is a molten steel passing mass [t/min].

5. The mold according to claim 4, comprising an electromagnetic stirring apparatus having a direct current coil and an alternating current coil capable of applying a superposed magnetic field of direct current magnetic field and alternating magnetic field to the molten steel in the mold, outside a long side of the mold positioned above the discharge ports of the immersion nozzle, and an electromagnetic braking apparatus having a direct current coil capable of applying a direct current magnetic field to the molten steel in the mold, outside a long side of the mold positioned below the discharge ports of the immersion nozzle.

6. A continuous casting method using the immersion nozzle according to any one of claims 1 to 3, wherein

an index K of molten surface variation represented by the following equation (1) is adjusted to be within a range of 0.09 to 0.14:

$$K^2 = (L^2 + W^2/4) / TP^2 \quad \ldots\ldots (1),$$

wherein L is a distance [m] from a meniscus to the upper end of the upper end of the discharge port in the immersion nozzle, W is a distance [m] between short sides of the mold at the position of the meniscus, and TP is a molten steel passing mass [t/min].

7. The continuous casting method of steel according to claim 6, comprising

applying a magnetic field obtaining by superposing an alternating magnetic field having a magnetic flux density of 0.03 to 0.1 T on a direct current magnetic field having a magnetic flux density of 0.1 to 0.8 T to the molten steel in the mold positioned above the discharge ports of the immersion nozzle immersed in the molten steel in the mold and applying a direct current magnetic field having a magnetic flux density of 0.1 to 0.8 T to the molten steel in the mold positioned below the discharge ports.

8. The continuous casting method of steel according to claim 6 or 7, comprising flowing an Ar gas from a tundish upper nozzle while controlling a ratio Q_{Ar} / TP of an Ar gas flow rate Q_{Ar} [NL/min] to a molten steel passing mass TP [t/min] within 2.0 to 5.0 inclusive.

Fig. 1

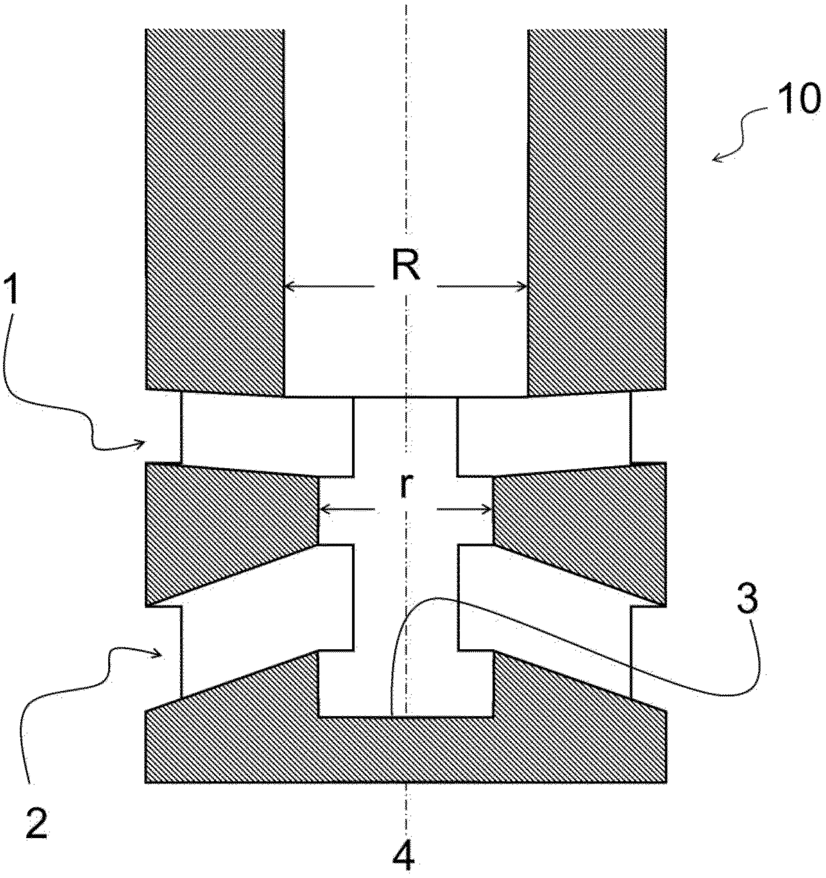


Fig. 2

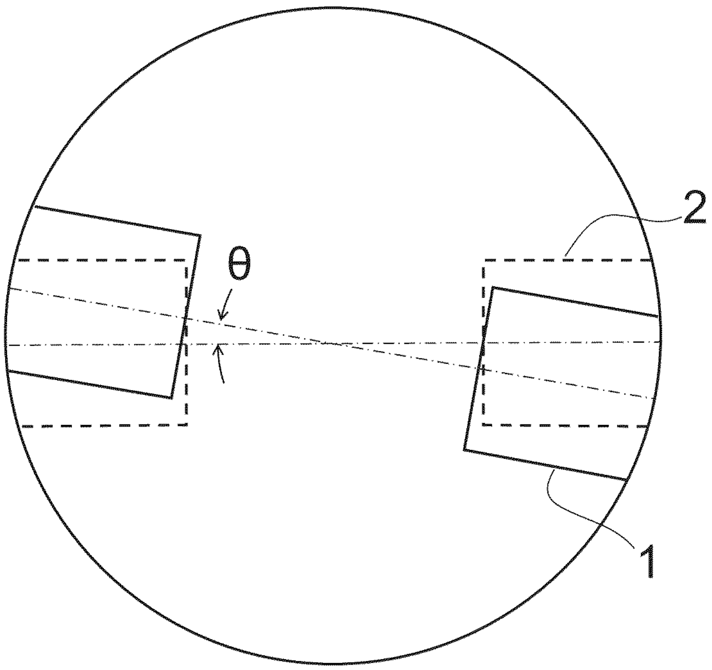
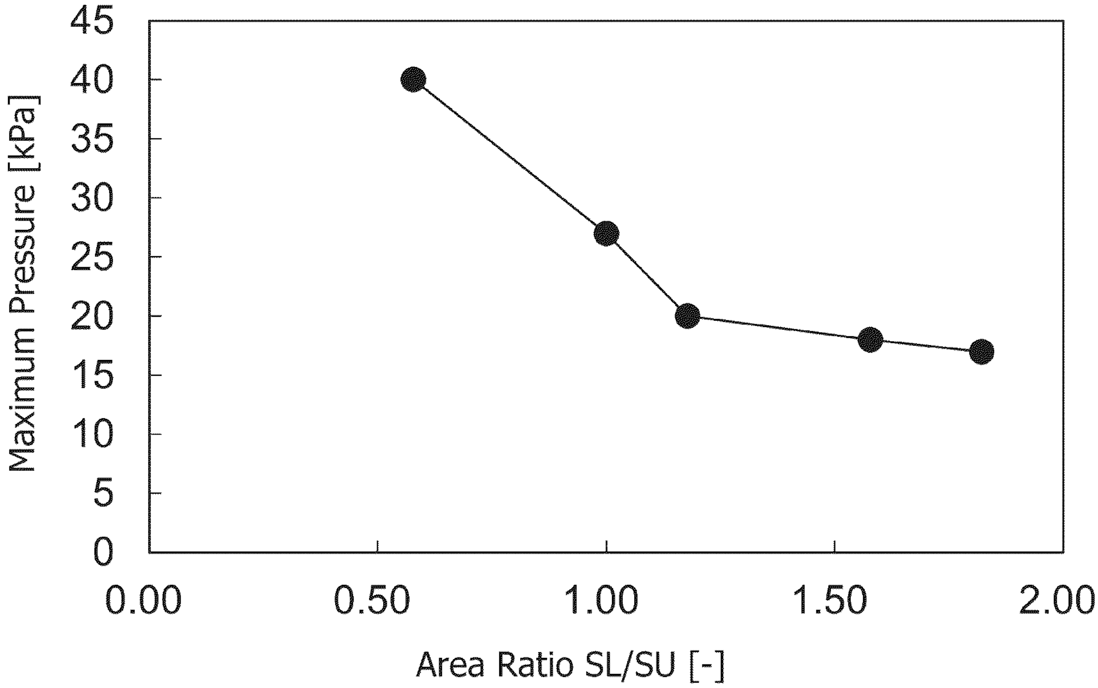


Fig. 3


45
40
35
30
25
20
15
10
5
0
Maximum Pressure [kPa]
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0.50
1.00
1.50
2.00
Area Ratio SL/SU [-]

Fig. 4

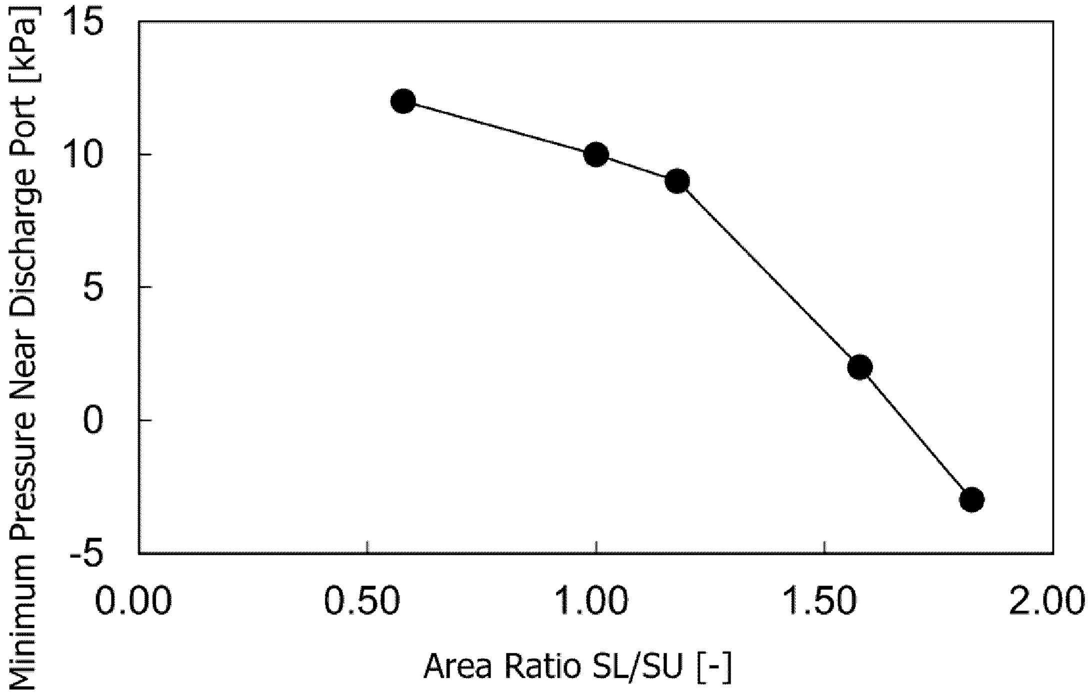

15
10
5
0
-5
Minimum Pressure Near Discharge Port [kPa]
0.00
0.50
1.00
1.50
2.00
Area Ratio SL/SU [-]

Fig. 5

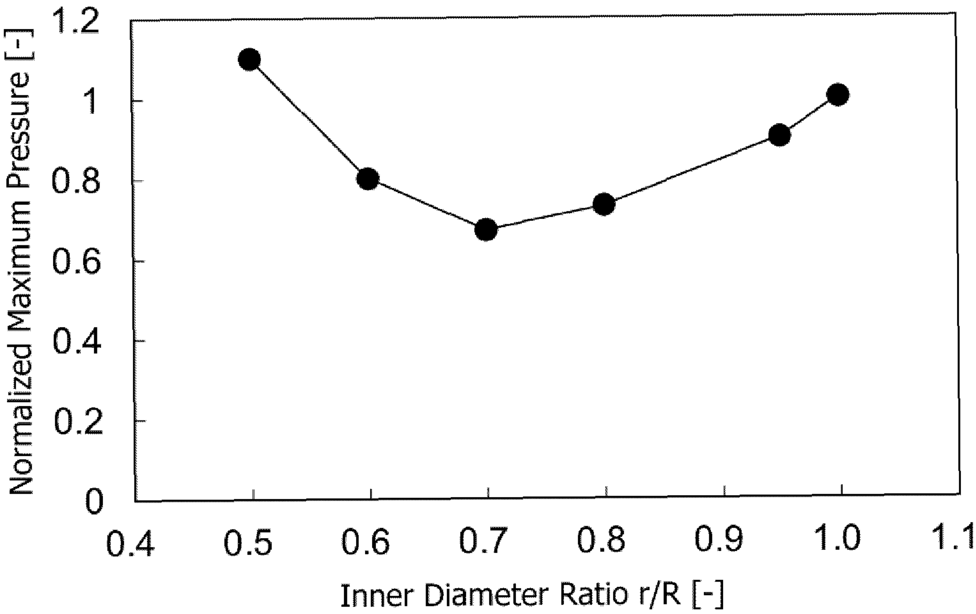
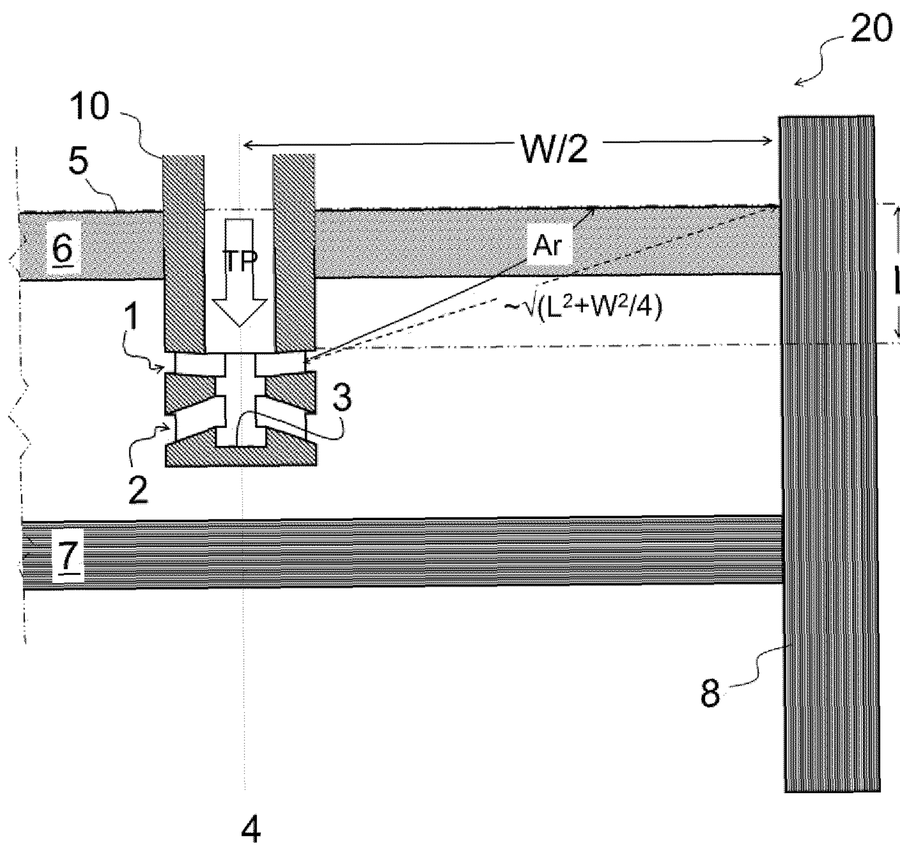

Normalized Maximum Pressure [-]
1.2
1
0.8
0.6
0.4
0.2
0
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
Inner Diameter Ratio r/R [-]

Fig. 6


20
10
5
W/2
6
TP
Ar
L
~√(L²+W²/4)
1
3
2
7
8
4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2023/011462

A. CLASSIFICATION OF SUBJECT MATTER

B22D 11/10(2006.01)i; ***B22D 41/50***(2006.01)i
FI: B22D11/10 330G; B22D11/10 330E; B22D11/10 330F; B22D11/10 360C; B22D41/50 520

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)

B22D11/10; B22D41/50

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2023
Registered utility model specifications of Japan 1996-2023
Published registered utility model applications of Japan 1994-2023

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.
X	JP 2019-063851 A (JFE STEEL CORP) 25 April 2019 (2019-04-25) claims, paragraphs [0031]-[0043], [0046]-[0063], fig. 1	1-3
Y		4-8
Y	JP 2015-085370 A (JFE STEEL CORP) 07 May 2015 (2015-05-07) claims, paragraphs [0041]-[0042], [0047]-[0048]	4-8
Y	JP 2016-073990 A (NIPPON STEEL & SUMITOMO METAL CORP) 12 May 2016 (2016-05-12) paragraph [0049]	4-8
Y	JP 4569715 B1 (JFE STEEL CORP) 27 October 2010 (2010-10-27) claims, paragraphs [0093], [0097], [0101], [0105]	5, 7-8
A	JP 2-295654 A (KAWASAKI STEEL CORP) 06 December 1990 (1990-12-06) p. 3, upper right column, line 13 to p. 3, lower right column, line 16, fig. 1-3	1-8

☐ 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
01 June 2023	**20 June 2023**

Name and mailing address of the ISA/JP	Authorized officer
Japan Patent Office (ISA/JP) **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Telephone No.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2023/011462

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 2019-063851 A	25 April 2019	(Family: none)	
JP 2015-085370 A	07 May 2015	(Family: none)	
JP 2016-073990 A	12 May 2016	(Family: none)	
JP 4569715 B1	27 October 2010	US 2012/0291982 A1 claims, paragraphs [0102], [0103], [0104], [0105] EP 2500120 A1 CN 102413963 A KR 10-2012-0062025 A RU 2012123986 A BR 112012011137 A	
JP 2-295654 A	06 December 1990	(Family: none)	

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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