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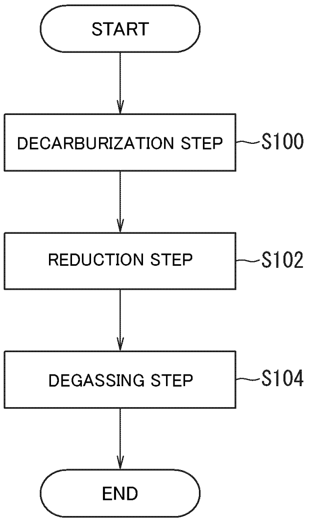
(54) METHOD FOR MANUFACTURING HIGH MANGANESE STEEL INGOT

(57) Provided is a method for refining a high manganese steel by which when refining a high manganese steel containing 5% by mass or more of manganese, high manganese yield can be obtained, and high productivity can be performed. The method includes, when refining a steel containing 5% by mass or more of manganese, a decarburization step (step S100) of performing a decarburization treatment on a hot metal (molten metal (2)) in a converter (1) to make the hot metal into a molten steel (molten metal (2)) having a low carbon concentration, a reduction step (step S102) of performing a reduction treatment on the molten steel by adding a manganese source and a silicon source to the molten steel kept in the converter (1) after the decarburization step, and a degassing step (step S104) of performing a vacuum degassing treatment on the molten steel by a vacuum degassing device (5) after the reduction step, in which, in the reduction step, the manganese source is added in accordance with a target manganese concentration in the steel, and the silicon source is added so as to satisfy Formula (1).

FIG. 1



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Description

Technical Field

[0001] The present invention relates to a method for refining a high manganese steel.

Background Art

[0002] Manganese is advantageous in that addition of manganese to steel improves strength of steel material. Other advantages of manganese include suppressing influence of sulfur on steel material by reacting with sulfur remaining as an unavoidable impurity in steel to form MnS so as to prevent formation of harmful FeS. Due to that, most steel materials contain manganese. In recent years, for the purpose of weight reduction of structures, low carbon and high manganese steels having low carbon content and high manganese content have been developed that have achieved both high tensile strength and high workability. These steels are widely used for line pipe steel plates, automobile steel plates, and the like.

[0003] In steelmaking processes, typical manganese sources used for adjustment of manganese concentration in molten steels are manganese ore, high carbon ferromanganese (carbon content: 7.5% by mass or less), medium carbon ferromanganese (carbon content: 2.0% by mass or less), low carbon ferromanganese (carbon content: 1.0% by mass or less), silicomanganese (carbon content: 2.0% by mass or less), metal manganese (carbon content: 0.01% by mass or less), and the like. Additionally, in these manganese sources, the lower the carbon content, the higher the cost, with the exception of manganese ore. Accordingly, to reduce production cost, there have been proposed methods for refining a manganese-containing steel by using manganese ore or high carbon ferromanganese as a low-cost manganese source.

[0004] For example, PTL 1 has proposed a method for refining a high manganese steel. In the method, after completion of blowing in a converter, a rinsing treatment using a bottom-blowing gas is performed. Then, when tapping molten steel into a ladle, a high carbon ferromanganese having a carbon concentration of 1.0% by mass or more is first charged, and next, aluminum is charged to perform a deoxidation treatment, followed by an RH gas degassing treatment.

[0005] In addition, PTL 2 has proposed a method for refining a high manganese steel. In the method, with use of manganese ore, decarburization refining of a hot metal is performed while reducing the manganese. After completion of the decarburization, molten steel is transported to a vacuum degassing facility, without performing a deoxidation treatment of the molten steel using aluminium. Then, a mixed gas of oxygen gas and inert gas is blown on the molten steel to perform a decarburization treatment.

[0006] Furthermore, PTL 3 has proposed a method for refining a high manganese steel. In the method, when performing decarburization refining of a high Mn hot metal having a manganese concentration of 8% by mass or more under reduced pressure until the carbon concentration becomes 0.1% by mass or less, a powdery decarburization refining additive containing a Mn oxide is sprayed on the hot metal by using a refining gas as a carrier gas.

Citation List

Patent Literature

[0007]

PTL 1: JP 2013-112855 A
PTL 2: Japanese Patent No. 4534734
PTL 3: JP H05-125428

Summary of Invention

Technical Problems

[0008] Incidentally, in the methods for refining a high manganese steel of PTL 1 to PTL 3, the manganese concentration in the molten steel is increased by reducing the manganese ore charged in the converter at the time of decarburization blowing of the hot metal in the converter or adding a manganese source to the molten steel at the time of molten steel tapping from the converter, ladle refining, or vacuum degassing refining.

[0009] However, in such refining methods, when a manganese source is added at the time of decarburization blowing or molten steel tapping from the converter, yield of the added manganese source is low, and therefore, it is necessary to add a large amount of the manganese source, whereby increased treatment time and increased manganese cost become problems. Additionally, when adding a manganese source at the time of molten steel tapping, ladle refining, or vacuum degassing refining, heat loss occurs due to dissolution of the manganese source, and thus, the molten steel needs to be heated in a process after treatment in the converter. However, heat treatment of the molten steel by a ladle refining device or a vacuum degassing device is less efficient than heat treatment in the converter, which is a problem in terms of increased treatment cost. Particularly, in high manganese steels having a manganese concentration of 5% by mass or more, these problems are noticeable.

[0010] Accordingly, the present invention has been made in view of the above problems, and it is an object of the present invention to provide a method for refining a high manganese steel by which when refining a high manganese steel containing 5% by mass or more of manganese, high manganese yield can be obtained, and high productivity can be performed.

Solution to Problems

[0011] According to an aspect of the present invention, there is provided a method for refining a high manganese steel including, when refining a steel containing 5% by mass or more of manganese, a decarburization step of performing a decarburization treatment on a hot metal in a converter to make the hot metal into a molten steel having a low carbon concentration, a reduction step of performing a reduction treatment on the molten steel by adding a manganese source and a silicon source to the molten steel kept in the converter after the decarburization step, and a degassing step of performing a vacuum degassing treatment on the molten steel by a vacuum degassing device after the reduction step, in which, in the reduction step, the silicon source is added in accordance with an added amount of the manganese source so as to satisfy Formula (1):

$$0.013\times\frac{W_{Mn}\times x_{Mn}}{x_{Si}}\leq W_{Si}\leq 0.150\times\frac{W_{Mn}\times x_{Mn}}{x_{Si}}\quad\cdot\cdot\cdot\ (1)$$

X_{Mn}: Manganese concentration (% by mass) in manganese source
X_{Si}: Silicon concentration (% by mass) in silicon source
W_{Mn}: Added amount (kg/t) of manganese source
W_{Si}: Added amount (kg/t) of silicon source

Advantageous Effects of Invention

[0012] According to an aspect of the present invention, there is provided a method for refining a high manganese steel by which when refining a high manganese steel containing 5% by mass or more of manganese, high manganese yield can be obtained, and high productivity can be performed.

Brief Description of Drawings

[0013]

FIG. 1 is a flowchart illustrating a method for refining a high manganese steel according to an aspect of the present invention;
FIG. 2 is a schematic diagram illustrating a converter; and
FIG. 3 is a schematic diagram illustrating a vacuum degassing device.

Description of Embodiments

[0014] In the following detailed description, to provide a thorough understanding of the present invention, numerous specific details will be described by exemplifying embodiments of the present invention. However, it is apparent that one or more embodiments will be implemented without description of the specific details. Additionally, for simplicity, known structures and devices in the drawings are schematically illustrated.

<Method for Refining High Manganese Steel>

[0015] A method for refining a high manganese steel according to an embodiment of the present invention will be described with reference to FIG. 1 to FIG. 3. In the present embodiment, a high manganese steel that is a molten steel containing 5% by mass or more of manganese is refined by performing a refining treatment to be described later on a hot metal tapped from a blast furnace.

[0016] First, as illustrated in FIG. 1 and FIG. 2, a decarburization step is executed (S100) that is configured to perform a decarburization treatment on a molten metal 2 (also referred to as "molten iron") that is a hot metal kept in a converter 1.

[0017] The molten metal 2 is the hot metal tapped from a blast furnace. After being tapped from the blast furnace, the molten metal 2 is transported to a steelmaking plant that is a next step by a transportation vessel capable of keeping hot metal, such as a hot metal pot or a torpedo car. Note that, to reduce an amount of a solvent such as a lime source for use in the converter 1, a dephosphorization treatment is preferably performed to reduce a phosphorus concentration in the hot metal before charging the hot metal in the converter 1. In the dephosphorization treatment, an oxygen source, such as solid oxygen such as iron oxide or gaseous oxygen, and a lime-containing solvent are added to the hot metal kept in the hot metal transportation vessel. Then, the hot metal is stirred by the gaseous oxygen and a stirring gas to allow dephosphorization reaction to proceed. Note that, in the dephosphorization treatment, to minimize the amount of the solvent to be used in the converter 1, the phosphorus concentration in the hot metal is preferably set to be lower than an upper limit concentration of a final component specification of the high manganese steel. Furthermore, there is a concern about increase in the phosphorus concentration due to a phosphorus pickup from a manganese source added in a post-step into the hot metal and rephosphorization from slag. Thus, more preferably, the dephosphorization treatment is performed until the phosphorus concentration in the hot metal becomes lower by around 0.05% by mass than an upper component specification limit, and then, a slag generated in the treatment is removed (also referred to as "slagged off") . Still furthermore, to set the phosphorus concentration in the hot metal to be lower than the upper component specification limit, preferably, a desiliconization treatment is performed before the dephosphorization treatment to previously remove silicon that inhibits efficient dephosphorization reaction.

[0018] In the decarburization step, before performing the decarburization treatment, the molten metal 2 that is the hot metal transported by the transportation vessel is transferred to the hot metal pot, and then charged into the converter 1 that is a primary refining furnace. Note that scraps that are used as an iron source may be charged into a furnace body 10 before charging the molten metal 2.

[0019] The converter 1 is an ordinary converter facility, and includes the furnace body 10, a top-blowing lance 11, a plurality of bottom-blowing nozzles 12, and a chute 13, as illustrated in FIG. 2. The furnace body 10 is a barrel-shaped or pear-shaped refining furnace having a furnace throat as an opening portion at a top thereof, and a refractory is provided thereinside. The top-blowing lance 11 is arranged above the furnace body 10, and configured to be movable up and down in a vertical direction (an up and down direction in FIG. 2). The top-blowing lance 11 includes a plurality of nozzle holes at a lower end thereof, and blows an oxidizing gas containing at least oxygen supplied from an unillustrated supply facility into the molten metal 2 kept in the furnace body 10 from the plurality of nozzle holes. The plurality of bottom-blowing nozzles 12 is provided at a bottom portion of the furnace body 10, and blows a stirring gas that is an inert gas such as argon or nitrogen supplied from an unillustrated supply device into the molten metal 2 kept in the furnace body 10 to stir the molten metal 2. The chute 13 is arranged above the furnace body 10, and connected to a plurality of unillustrated hoppers above the furnace storing various kinds of secondary raw materials such as the lime-containing solvent and alloy iron, through which chute 13 the secondary raw materials cut out from the respective furnace upper hoppers are added to an inside of the furnace body 10.

[0020] In the decarburization step, the oxidizing gas is blown (also referred to as "oxygen feed") into the molten metal 2 from the top-blowing lance 11 while stirring the molten metal 2 kept in the furnace body 10 by the stirring gas blown in from the bottom-blowing nozzles 12, whereby oxygen is supplied to the molten metal 2 to perform the decarburization treatment (also referred to as "decarburization blowing") under atmospheric pressure. In the decarburization blowing, the oxygen blown into the molten metal 2 by the top-blowing lance 11 reacts with carbon in the molten metal 2, whereby decarburization reaction proceeds. Note that when the component specification of the high manganese steel includes Cr and Ni (when addition thereof is essential), a secondary raw material such as alloy iron containing Cr and Ni is added to the molten metal 2 through the chute 13 during the decarburization blowing. In the decarburization step, the decarburization blowing is performed until the carbon concentration in the molten metal 2 falls in a predetermined range, as a result of which the molten metal 2 is made into a molten steel having a low carbon concentration from the hot metal having a high carbon concentration. In this case, the predetermined range of the carbon concentration is preferably from 0.05% by mass to 0.2% by mass. This is because when the carbon concentration in the molten metal 2 after the decarburization step is less than 0.05% by mass, the molten metal 2 has increased oxygen potential, which reduces yield of the manganese source. On the other hand, when the carbon concentration in the molten metal 2 after the decarburization step is more than 0.2% by mass, a decarburization treatment in a secondary refining step is necessary, therefore increasing treatment cost. Then, when the carbon concentration in the molten metal 2 falls in the predetermined range, the supply of the oxidizing gas into the furnace body 10 is stopped, and the decarburization step ends.

[0021] After the decarburization step, a reduction step is executed (S102) that is configured to perform a reduction treatment on the molten metal 2 that is the molten steel by adding a manganese source and a silicon source into the furnace body 10 keeping the molten metal 2. The manganese source is an ore, an alloy, or a metal that contains manganese. Examples of the manganese source usable include manganese ore, high carbon ferromanganese, medium carbon ferromanganese, low carbon ferromanganese, silicomanganese, and metal manganese. The silicon source is an ore, an alloy, or a metal that contains silicon (silicon). Examples of the silicon source usable include ferrosilicon and silicomanganese. The manganese source and the silicon source may be added from the furnace throat through the chute 13, or may be added from the furnace throat of the furnace body 10 by using a scrap chute (unillustrated) used for charging scraps. Furthermore, when adding the manganese source and the silicon source, the addition is performed while stirring the molten metal 2 by blowing the stirring gas from the plurality of bottom-blowing nozzles 12.

[0022] In the reduction step, the manganese source is added in an amount of addition in accordance with a target manganese concentration that is the component specification of the high manganese steel. In other words, the added amount of the manganese source is determined by a manganese content of the manganese source, the carbon concentration in the molten metal 2, and the like, in accordance with the target manganese concentration. In this case, a yield performance of the manganese source may be taken into consideration. Additionally, in the reduction step, the manganese concentration in the molten metal 2 does not have to be set to the target concentration. The manganese concentration in the molten metal 2 may be set to a lower concentration than the target concentration so that it is adjustable in the degassing step to be described later. Note that, from the viewpoint of thermal efficiency, the added amount of the manganese source in the reduction step is preferably increased as much as possible with respect to the added amount of the manganese source in the degassing step. Furthermore, from the viewpoint of reduction of treatment cost, it is preferable to use a manganese ore or a low-cost manganese source having a high carbon concentration as much as possible unless it affects adjustment of components other than manganese, such as carbon.

[0023] The silicon source is added in an added amount such that the following Formula (1) is satisfied. In Formula (1), X_{Mn} represents a manganese concentration (% by mass) in the manganese source, X_{Si} represents a silicon concentration (% by mass) in the silicon source, W_{Mn} represents an added amount (kg/t) of the manganese source, and W_{Si} represents an added amount (kg/t) of the silicon source. In other words, the silicon source is added by an amount in accordance with the added amount of the manganese source to be added.

$$0.013 \times \frac{W_{Mn} \times x_{Mn}}{x_{Si}} \leq W_{Si} \leq 0.150 \times \frac{W_{Mn} \times x_{Mn}}{x_{Si}} \quad \cdots \quad (1)$$

[0024] In addition, in the reduction step, after adding the manganese source and the silicon source, the stirring gas is blown in from the plurality of bottom-blowing nozzles 12 to stir the molten metal 2 for a predetermined time.

[0025] Here, the molten metal 2 after the decarburization step has high oxygen potential. Thus, when the manganese source is added to the molten metal 2, manganese in the manganese source is not retained in the molten metal 2 and oxidized to become manganese oxide (MnO), which is included in a slag 3. However, in the present embodiment, the silicon source also is added in addition to the manganese source. Thus, the manganese in the manganese source and the manganese oxide in the slag 3 generated by the decarburization step are reduced by a reaction represented by the following Formula (2), thereby increasing the manganese concentration in the molten metal 2. Additionally, silicon in the silicon source is preferentially oxidized, thereby decreasing the oxygen potential of the molten metal 2. As a result, the manganese in the manganese source is easily retained in the molten metal 2, so that the manganese concentration in the molten metal 2 is increased.

$$2(MnO) + [Si] = (SiO_2) + 2[Mn] \quad \ldots \quad (2)$$

[0026] Furthermore, in the reduction step, preferably, lime is added in the furnace body 10 such that a basicity (CaO/SiO_2) of the slag 3, which is defined as a ratio of a CaO concentration (% by mass) to an SiO_2 concentration (% by mass) in the slag 3, is from 1.6 from 2.4. This promotes formation of the slag 3 and desulfurization of the molten metal 2 represented by the following Formula (3):

$$2[S] + [Si] + 2(CaO) = 2(CaS) + (SiO_2) \quad \ldots \quad (3)$$

[0027] Note that when the added amount of the silicon source is lower than the range of Formula (1), i.e., when the added amount of the silicon source is small, the reduction reaction of the manganese oxide does not proceed, and therefore, the manganese concentration in the molten metal 2 cannot be increased. On the other hand, when the added amount of the silicon source is higher than the range of Formula (1), i.e., when the added amount of the silicon source is large, the added amount of the lime for adjusting the basicity becomes too much, which increases refining treatment cost. Additionally, when the added amount of the silicon source is large, the silicon concentration in the molten metal 2 increases, and may exceed the upper component specification limit. Such a case is not preferable, since it is necessary to perform a desiliconization treatment for reducing the silicon concentration in the molten metal 2 in the next step.

[0028] Still furthermore, in the reduction step, after completion of the reduction treatment, the molten metal 2 in the furnace body 10 is transferred to a ladle (also referred to as "steel tapping"). In this case, preferably, lime is previously pre-charged in an amount of from 5 kg/t to 10 kg/t per ton of the molten metal in the ladle. Pre-charging lime in the ladle can prevent generation of white smoke at a time of steel tapping, as well as can suppress increase in sulfur concentration in the molten metal 2 due to resulfurization from the slag 3.

[0029] After the reduction step, the degassing step is executed (S104) that is configured to perform a vacuum degassing treatment on the molten metal 2 that is the molten steel by a vacuum degassing device 5. The vacuum degassing device 5 is a VOD-type degassing device, and performs the degassing treatment by stirring the molten metal 2 kept in a ladle 4 under reduced pressure. The vacuum degassing device 5 includes a vacuum tank 50, an exhaust pipe 51, a stirring gas supply path 52, a top-blowing lance 53, and a supply port 54. The vacuum tank 50 is a container that can store the ladle 4 in an inside thereof, and includes a detachable upper lid 500 so that the ladle 4 can be taken into and take out from the inside thereof. The exhaust pipe 51 is provided on a side face of the vacuum tank 50, and connected to an unillustrated exhaustion device. The stirring gas supply path 52 is arranged from an inside of the vacuum tank 50 to the inside thereof, and a leading end of the stirring gas supply path 52 in the inside of the vacuum tank 50 is connected to a blowing-in port 40 of the ladle 4. Additionally, a leading end of the stirring gas supply path 52 in the inside of the vacuum tank 50 is connected to an unillustrated stirring gas supply device to supply a stirring gas, such as argon gas, supplied from the stirring gas supply device to the blowing-in port 40 of the ladle 4. The top-blowing lance 53 is inserted into the center of the upper lid 500, and configured to be movable up and down in a vertical direction (an up and down direction in FIG. 3). In addition, the top-blowing lance 53 includes a nozzle hole formed at a lower end thereof, and blows an oxidizing gas containing at least oxygen supplied from an unillustrated supply facility from the nozzle hole to the molten metal 2 kept in the ladle 4. The supply port 54 is formed in the upper lid 500, and is a charging port connected to a plurality of unillustrated hoppers above the furnace storing various kinds of secondary raw materials such as a lime-containing solvent and alloy iron to add the secondary raw material cut out from each hopper above the furnace to the molten metal 2 kept in the ladle 4.

[0030] In the degassing step, the ladle 4 is put into the vacuum tank 50. Then, while stirring the molten metal 2 by blowing the stirring gas from the blowing-in port 40, exhaust gas is discharged from the exhaust pipe 51 by using the exhaustion device to reduce pressure inside the vacuum tank 50, thereby performing the vacuum degassing treatment. By performing such a vacuum degassing treatment, removal of gaseous components (nitrogen, hydrogen, and the like) in the molten metal 2, homogenization of components in the molten metal 2, removal of inclusions and the like in the molten metal 2, temperature adjustment of the molten metal 2, and the like are achieved. In addition, in the degassing step, when performing the vacuum degassing treatment, secondary raw material(s) for component adjustment is (are) added to the molten metal 2 through the supply port 54 so as to achieve a target component range, in accordance with components of the molten metal 2 before or during the vacuum degassing treatment. In this case, when the manganese concentration in the molten metal 2 before the vacuum degassing treatment is lower than a target concentration, a manganese source, such as metal manganese, high carbon ferromanganese, and/or low carbon ferromanganese, is added to the molten metal 2 by an amount necessary for component adjustment. In addition, when it is necessary to adjust component (s) such as Al, Ni, Cr, Cu, Nb, Ti, V, Ca, and/or B, secondary raw material(s) containing each component are added to the molten metal 2. Furthermore, for desulfurization or the like, secondary raw material(s) for use in composition adjustment of the slag 3 and promotion of desulfurization reaction, such as CaO-containing substance(s), MgO-containing substance(s), aluminium-containing substance(s), Al_2O_3-containing substance (s), and/or SiO_2-containing substance (s), may be added to the molten metal 2.

[0031] Additionally, in the degassing step, preferably, the molten metal 2 is stirred under a condition where a stirring power ε (W/t) represented by the following Formula (4) is from 300 W/t to 1300 W/t. It is not preferable when the stirring power ε is less than 300 W/t, since stirring force becomes small, which takes time to perform denitrification treatment and dehydrogenation treatment, so that treatment time of the vacuum degassing treatment is prolonged. It is also not preferable when the stirring power ε is more than 1300 W/t, since an amount of the slag 3 included in the molten metal 2 increases, thereby increasing defect rate due to slag-based inclusions. Note that, in Formula (4), Q_n represents a steering gas flow rate (Nm^3/min) , T_1 represents a temperature (K) of the molten metal 2, W_m represents a weight (t) of the molten metal 2, ρ_1 represents a density (kg/m^3) of the molten metal 2, h represents a molten metal surface height (m) that is a depth of the molten metal 2 in the ladle 4, P_1 represents an atmospheric pressure (Torr), η represents an energy transfer efficiency (-), and T_n represents a temperature (K) of the stirring gas. Additionally, 1 Torr is (101325/760) Pa.

$$\varepsilon=\frac{371\times Q_n\times T_l}{W_m}\left\{\ln\left(1+\frac{9.8\times\rho_l\times h}{P_1}\right)+\eta\left(1-\frac{T_n}{T_l}\right)\right\}\quad\cdots\ (4)$$

[0032] Furthermore, in the degassing step, when the temperature of the molten metal 2 is lower than a target temperature after completion of the degassing step, a temperature increasing treatment may be performed to increase the temperature of the molten metal 2 during the vacuum degassing treatment. In the temperature increasing treatment, aluminum is added to the molten metal 2 from the supply port 54, and then the oxidizing gas containing oxygen is blown into the molten metal 2 from the top-blowing lance 53. By doing this, the aluminum in the molten metal 2 reacts with the oxygen in the oxidizing gas, thereby enabling increase in the temperature of the molten metal 2. Note that, in the temperature increasing treatment, a dynamic pressure P (kPa) of a jet flow of the oxidizing gas blown from the top-blowing lance 53, which is calculated by Formula (5) and Formula (6), is preferably controlled to be from 10 kPa to 50 kPa. When the dynamic pressure P is controlled to be within the above range, the molten metal 2 can be efficiently heated while minimizing evaporation of manganese from the molten metal 2. Note that ρ_g and U in Formula (5) represent a density (kg/Nm^3) of the oxidizing gas and a flow velocity (m/sec), at a nozzle leading end, of the oxidizing gas blown from the nozzle of the top-blowing lance 53, respectively. In addition, F and S in Formula (6) represent a flow rate (Nm^3/h) of the oxidizing gas and a cross-sectional area (m^2) of the nozzle of the top-blowing lance 53, respectively.

$$P=\frac{\rho_g U^2}{2}\quad\cdots\ (5)$$

$$U=\frac{F}{S}\times\frac{1}{3600}\quad\cdots\ (6)$$

[0033] By going through the degassing step, a molten steel having a predetermined target component concentration is refined. Note that after the degassing step, continuous casting of the refined molten steel is performed to manufacture cast pieces of high manganese steel having a predetermined shape, such as slabs.

<Modifications>

[0034] While the present invention has been described with reference to the specific embodiment hereinabove, it is not intended to limit the present invention by the descriptions. In addition to the disclosed embodiment, other embodiments of the present invention including various modifications will be apparent to those skilled in the art by referring to the description of the present invention. Thus, it should be understood that embodiments of the present invention described in the claims encompass embodiments including the modifications described in the present specification, alone or in combination.

[0035] For example, while the above-described embodiment has used the VOD-type refining device as the vacuum degassing device 5, the present invention is not limited thereto. For example, the vacuum degassing device 5 may be an RH-type degassing device or a DH-type degassing device. Note that when the vacuum degassing device is an RH-type degassing device, a reflux rate Q (t/min) of the molten steel represented by the following Formula (7) is preferably set to be from 150 t/min to 200 t/min under a condition where a tank inner space pressure of the vacuum tank is from 50 Torr to 100 Torr so that the evaporation of manganese is suppressed. Note that when denitrification and dehydrogenation of the molten steel are necessary, treatment may be performed at a tank inner space pressure of less than 50 Torr, but after the denitrification and dehydrogenation, it is preferable to perform treatment at a tank inner space pressure of from 50 Torr to 100 Torr. In Formula (7), K represents a constant, G represents a flow rate (NL/min) of a blowing gas for reflux blown in from an immersion tube, D represents an inner diameter (m) of the immersion tube, P_2 represents an external pressure (Torr), and P_3 represents a tank inner space pressure (Torr) of the vacuum tank.

$$Q=KG^{1/3}D^{4/3}\left(\ln\left(\frac{P_2}{P_3}\right)\right)^{1/3}\quad\cdots\ (7)$$

[0036] In addition, while it has been described in the above embodiment that only the molten metal 2 that is a molten steel produced in the converter 1 is used as the molten metal 2 to be treated by the vacuum degassing device 5, the present invention is not limited thereto. For example, a combined molten metal of a molten steel produced in the converter 1 and a molten steel refined in another refining furnace may be used as the molten metal 2 to be treated by the vacuum degassing device 5. In this case, increasing the manganese concentration in the molten steel refined in the other refining furnace enables reduction of the manganese concentration in the molten steel produced in the converter 1.

[0037] Furthermore, in the above embodiment, it has been described that, in the reduction step, after addition of the manganese source and the silicon source, the stirring gas is blown in from the plurality of bottom-blowing nozzles 12 to stir the molten metal 2 for the predetermined time. However, the present invention is not limited thereto. In the reduction step, the oxidizing gas from the top-blowing lance 11 may be blown in addition to the blowing-in of the stirring gas. Particularly, when it is necessary to increase the temperature of the molten metal 2, heat treatment may be performed by oxidization reaction with the oxidizing gas.

[0038] Still furthermore, while it has been described in the above embodiment that the hot metal is subjected to the dephosphorization treatment before the decarburization treatment, the present invention is not limited thereto. For example, before the decarburization treatment, a desulfurization treatment may be performed to reduce sulfur concentration in the hot metal, in addition to the dephosphorization treatment. The desulfurization treatment may be performed before or after the dephosphorization treatment, in accordance with facility structure.

[0039] Additionally, while it has been described in the above embodiment that the dephosphorization treatment is performed on the hot metal kept in the hot metal transportation vessel, the present invention is not limited thereto. For example, dephosphorization treatment may be performed by blowing an oxidizing gas from a top-blowing lance into hot metal kept in a converter-type refining furnace.

<Effects of Embodiment>

[0040]

(1) The method for refining a high manganese steel according to an aspect of the present invention includes, when refining a steel containing 5% by mass or more of manganese, the decarburization step (step S100) of performing the decarburization treatment on a hot metal (molten metal 2) in the converter 1 to make the hot metal into a molten steel (molten metal 2) having a low carbon concentration, the reduction step (step S102) of performing the reduction treatment on the molten steel by adding a manganese source and a silicon source to the molten steel kept in the converter 1 after the decarburization step, and the degassing step (step S104) of performing the vacuum degassing treatment on the molten steel by the vacuum degassing device 5 after the reduction step. In the reduction step, the manganese source is added in accordance with a target manganese concentration in the steel, and the silicon source is added so as to satisfy Formula (1).

According to the above structure (1), the reduction reaction of Formula (2) can be promoted, so that manganese in the added manganese source can be easily retained in the molten metal 2. Additionally, since the addition of the manganese source is performed in the converter 1, heat loss (reduced temperature of the molten metal 2) due to the addition of the manganese source can be suppressed. In addition, since the molten metal 2 can be subjected to heat treatment in the converter 1 after the addition of the manganese source, the heat treatment can be efficiently performed. Furthermore, excessive addition of the silicon source can be suppressed that is equal to or more than an amount sufficient to promote reduction reaction, so that it is unnecessary to perform desiliconization treatment in the degassing step. As a result, the degassing step can be efficiently performed in a short treatment time. As the degassing treatment time becomes longer, treatment cost increases, as well as production efficiency decreases. In other words, according to the above structure (1), when refining a high manganese steel containing 5% by mass or more of manganese, high manganese yield can be obtained, and the high manganese steel can be refined with high productivity.

(2) In the above structure (1), the vacuum degassing device 5 used is a device configured to stir the molten steel by blowing a stirring gas from the bottom of a ladle keeping the molten steel, and, in the degassing step, the vacuum degassing treatment is performed while stirring the molten steel under the condition where the stirring power ε represented by Formula (4) is from 300 W/t to 1300 W/t.

[0041] According to the above structure (2), the time necessary for denitrification treatment and dehydrogenation treatment can be shortened, and moreover, inclusion of the slag 3 in the molten metal 2 can be suppressed. Thus, treatment time of the vacuum degassing treatment can be shortened.

Example 1

[0042] Next, a description will be given of Example 1 conducted by the present inventors. In Example 1, a hot metal pretreatment of desiliconization treatment and dephosphorization treatment was performed on a hot metal tapped from a blast furnace to give a phosphorus concentration of 0.010% by mass. The resulting hot metal was subjected to the decarburization step, the reduction step, and the degassing step in the same manner as the above embodiment to refined high manganese steels having a manganese concentration of 5% by mass or more. Note that components of the refined high manganese steels were as follows: carbon concentration 0.145% by mass to 0.155% by mass; manganese concentration 24% by mass to 25% by mass; silicon concentration 0.1% by mass to 0.2% by mass; sulfur concentration 0.002% by mass or less; nitrogen concentration 100 ppm or less; and hydrogen concentration 5 ppm or less.

[0043] In the decarburization step, decarburization treatment was performed on the molten metal 2 that was the hot metal subjected to the hot metal pretreatment, in the same manner as the above embodiment. Decarburization blowing was performed until the carbon concentration became 0.05% by mass to obtain a molten steel.

[0044] In the reduction step, high carbon ferromanganese and metal manganese as a manganese source and ferrosilicon as a silicon source were added to the molten metal 2 that was the molten steel subjected to the decarburization treatment. Then, while stirring the molten metal 2 with a stirring gas, oxygen feed from the top-blowing lance 11 was additionally continued to perform reduction treatment, whereby the manganese source was dissolved to increase the manganese concentration in the molten metal 2. The added amount of the silicon source was set so as to satisfy Formula (1). Additionally, in the reduction step, lime was added together with the manganese source. The manganese concentration in the molten metal 2 at the time of completion of the reduction treatment was approximately 24% by mass. Furthermore, in the reduction step, when transferring (tapping) the molten metal 2 from the converter 1 into the ladle 4, approximately 0.8 kg of metal aluminum per ton of the molten steel was added to the molten metal 2 to be tapped.

[0045] In the degassing step, degassing treatment using the VOD-type vacuum degassing device 5 was performed on the molten metal 2 that was 150 tons of molten steel subjected to the reduction step, in the same manner as the above embodiment. In the degassing step, while stirring by blowing Ar gas at a flow rate of 2000 Nl/min from the blowing-in port 40 of the ladle 4 into the molten metal 2, the degassing treatment was performed at a tank inner space pressure of the vacuum tank 50 of 2 Torr. In addition, in the degassing step, metal manganese and high carbon ferromanganese were added to the molten metal 2 during the degassing treatment to make a component adjustment.

[0046] Additionally, in Example 1, for comparison, high manganese steels were refined also under conditions where the added amount of the silicon source did not satisfy Formula (1) in the reduction step (Comparative Example 1). Note that, in Comparative Example 1, conditions other than the added amount of the silicon source in the reduction step were all the same as those in Example 1.

[0047] Table 1 shows, as results of Example 1, added amount of the silicon source in the reduction step, Mn yield, silicon concentration in the molten metal 2 at a time of tapping, and time taken to perform the degassing treatment in the degassing step. Note that $0.013 \times W_{Mn} \times X_{Mn} / X_{Si}$ and $0.150 \times W_{Mn} \times X_{Mn} / X_{Si}$ in Table 1 represent a lower limit value and an upper limit value, respectively, in a range represented by Formula (1). As shown in Table 1, in Example 1, high manganese steels were refined under a total of 10 conditions consisting of 6 conditions of Examples 1-1 to 1-6 where the added amount W_{Si} of the silicon source was within the range of Formula (1) and 4 conditions of Comparative Examples 1-1 to 1-4 where the added amount W_{Si} of the silicon source was out of the range of Formula (1). Additionally, the Mn yield in Table 1 indicates how much manganese contained in the manganese source used in the reduction step was added to the molten metal 2, i.e., how much the manganese content in the manganese source contributed to increase in the manganese concentration in the molten metal 2 before and after the reduction step.

[Table 1]

	$0.013\times W_{Mn}\times x_{Mn}/x_{Si}$	$0.150\times W_{Mn}\times x_{Mn}\times x_{Si}$	W_{Si}	Mn yield	[Si] at time of tapping	Degassing treatment time
	kg/t	kg/t	kg/t	%	% by mass	min
Comparative Example 1-1	4.9	56	1	36	0.02	65
Comparative Example 1-2	4.9	56	3	46	0.03	63
Comparative Example 1-3	4.9	56	65	73	0.23	64
Comparative Example 1-4	4.9	56	70	74	0.25	70
Example 1-1	4.9	56	5	50	0.06	56

(continued)

	$0.013 \times W_{Mn} \times x_{Mn} / x_{Si}$	$0.150 \times W_{Mn} \times x_{Mn} \times x_{Si}$	W_{Si}	Mn yield	[Si] at time of tapping	Degassing treatment time
	kg/t	kg/t	kg/t	%	% by mass	min
Example 1-2	4.9	56	15	53	0.09	50
Example 1-3	4.9	56	25	55	0.10	46
Example 1-4	4.9	56	35	58	0.13	48
Example 1-5	4.9	56	45	61	0.16	48
Example 1-6	4.9	56	55	68	0.18	50

[0048] As shown in Table 1, under the conditions of Comparative Examples 1-1 and 1-2, the manganese yield was equal to or less than 46%, which was lower than under other conditions. This seems to be because the reduction reaction of the slag 3 represented by Formula (2) did not sufficiently proceed due to the small amount of the silicon source added. Since Comparative Examples 1-1 and 1-2 resulted in the low Mn yields, it was necessary to perform reduction treatment by adding the silicon source in the degassing step, and then adjust components and temperature, as a result of which the time taken to perform the degassing step was longer than in Examples 1-1 to 1-6.

[0049] Additionally, although the conditions of Comparative Examples 1-3 and 1-4 resulted in high manganese yields, the silicon concentration at the time of tapping exceeded 0.20% by mass, which was an upper specification limit. This seems to be because an amount of silicon equal to or more than an amount consumed by the reduction reaction of the slag 3 represented by Formula (2) and the desulfurization reaction represented by Formula (3) was supplied to the molten metal 2. Since Comparative Examples 1-3 and 1-4 resulted in the high silicon concentrations at the time of tapping, it was necessary to perform desiliconization treatment in the degassing treatment step, so that the time taken to perform the degassing step was longer than in Examples 1-1 to 1-6. Note that, in the desiliconization treatment, silicon contained in the molten metal 2 is oxidized and removed by blowing an oxidizing gas from the top-blowing lance 53 into the molten metal 2.

[0050] On the other hand, under the conditions of Examples 1-1 to 1-6, high manganese yields were obtained in the reduction step, and also, the silicon source was not added more than necessary, so that the silicon concentration at the time of tapping was able to be lowered. Thus, the time necessary for the degassing step was able to be shortened.

Example 2

[0051] Next, a description will be given of Example 2 conducted by the present inventors. In Example 2, high manganese steels were refined under a plurality of conditions where the stirring power ε in the degassing step was changed, by the same refining method as in Example 1-4. Note that components of the refined high manganese steels were as follows: carbon concentration 0.145% by mass to 0.155% by mass; manganese concentration 24% by mass to 25% by mass; silicon concentration 0.1% by mass to 0.2% by mass; sulfur concentration 0.002% by mass or less; nitrogen concentration 100 ppm or less; and hydrogen concentration 5 ppm or less.

[0052] Specifically, as the decarburization step, decarburization treatment was performed on the molten metal 2 that was a hot metal subjected to the hot metal pretreatment in the converter 1, similarly to Example 1-4. Decarburization blowing was performed until the carbon concentration became 0.05% by mass to obtain a molten steel. Next, as the reduction step, 35 kg/t of the silicon source was added to perform reduction treatment on the molten metal 2, similarly to Example 1-4. The manganese concentration in the molten metal 2 at the time of completion of the reduction treatment was approximately 24% by mass. Furthermore, as the degassing step, degassing treatment was performed on the molten metal 2 by the vacuum degassing device 5, similarly to Example 1-4. In the degassing step, the degassing treatment was performed under a plurality of conditions where the stirring power ε was optionally changed by adjusting the flow rate of Ar gas blown in from the blowing-in port 40 of the ladle 4.

[0053] Table 2 shows, as results of Example 2, added amount of the silicon source in the reduction step, Mn yield, silicon concentration in the molten metal 2 at the time of tapping, stirring power in the degassing step, and time taken to perform the degassing treatment in the degassing step. As shown in Table 2, in Example 2, the high manganese steels were refined under a total of 10 conditions of Examples 2-1 to 2-10 where the stirring powers in the degassing step were different. Note that the stirring power ε in the degassing step in Example 1-4 corresponds to that in Example 2-1. In addition, in Examples 2-1 to 2-10, refining conditions other than the conditions above were the same as those in Example 1-4.

[Table 2]

	$0.013\times W_{Mn}\times x_{Mn}/x_{Si}$	$0.150\times W_{Mn}\times x_{Mn}/x_{Si}$	W_{Si}	Mn yield	[Si] at time of tapping	Stirring power	Degassing treatment time
	kg/t	kg/t	kg/t	%	% by mass	W/t	min
Example 2-1	4. 9	56	35	58	0.13	226.1	48
Example 2-2	4. 9	56	35	57	0.13	282.6	47
Example 2-3	4.9	56	35	56	0.13	339.1	44
Example 2-4	4.9	56	35	58	0.13	538.7	42
Example 2-5	4.9	56	35	57	0.13	616.6	40
Example 2-6	4. 9	56	35	56	0.13	805.1	42
Example 2-7	4.9	56	35	56	0.13	1037.8	43
Example 2-8	4. 9	56	35	57	0.13	1141.5	45
Example 2-9	4.9	56	35	58	0.13	1375.0	47
Example 2-10	4. 9	56	35	59	0.13	1556.6	49

[0054] As shown in Table 2, under the conditions of Examples 2-3 to 2-8 where the stirring power ε was from 300 W/t to 1300 W/t, the time necessary for the degassing treatment was confirmed to be shorter than in Examples 2-1 and 2-2 where the stirring power ε was less than 300 W/t and Examples 2-9 and 2-10 where the stirring power ε was more than 1300 W/t. This seems to be because stirring by providing an appropriate stirring power to the molten metal 2 promoted dehydrogenation, denitrification, and floating of inclusions in the vacuum degassing treatment.

[0055] By contrast, under the conditions of Examples 2-1 and 2-2 where the stirring power ε was less than 300 W/t, stirring was weak, and therefore dehydrogenation and denitrification took time, which resulted in longer time to perform the degassing treatment. Additionally, under the conditions of Examples 2-9 and 2-10 where the stirring power ε was more than 1300 W/t, stirring was too strong. Therefore, the amount of the slag 3 included in the molten metal 2 increased, so that it took time to cause floating of slag-based inclusions in the molten metal 2, as a result of which the time necessary for the degassing treatment was prolonged.

Reference Signs List

[0056]

1: Converter
10: Furnace body
11: Top-blowing lance
12: Bottom-blowing nozzle
13: Chute
2: Molten metal
3: Slag
4: Ladle

40: Blowing-in port
5: Vacuum degassing device
50: Vacuum tank
51: Exhaust pipe
52: Stirring gas supply path
53: Top-blowing lance
54: Supply port

Claims

1. A method for refining a high manganese steel comprising: when refining a steel containing 5% by mass or more of manganese,
a decarburization step of performing a decarburization treatment on a hot metal in a converter to make the hot metal into a molten steel having a low carbon concentration;
a reduction step of performing a reduction treatment on the molten steel by adding a manganese source and a silicon source to the molten steel kept in the converter after the decarburization step; and
a degassing step of performing a vacuum degassing treatment on the molten steel by a vacuum degassing device after the reduction step,
wherein, in the reduction step, the silicon source is added in accordance with an added amount of the manganese source so as to satisfy Formula (1):

$$0.013\times\frac{W_{Mn}\times x_{Mn}}{x_{Si}}\leq W_{Si}\leq 0.150\times\frac{W_{Mn}\times x_{Mn}}{x_{Si}}\quad\cdots\ (1)$$

X_{Mn}: Manganese concentration (% by mass) in manganese source
X_{Si}: Silicon concentration (% by mass) in silicon source
W_{Mn}: Added amount (kg/t) of manganese source
W_{Si}: Added amount (kg/t) of silicon source

2. The method for refining a high manganese steel according to claim 1, wherein the vacuum degassing device used is a device configured to stir the molten steel by blowing a stirring gas from a bottom of a ladle keeping the molten steel, and wherein, in the degassing step, the vacuum degassing treatment is performed while stirring the molten steel under a condition where a stirring power ε represented by Formula (4) is from 300 W/t to 1300 W/t:

$$\varepsilon=\frac{371\times Q\times T_l}{W_m}\left\{\ln\left(1+\frac{9.8\times\rho_l\times h}{P_2}\right)+\eta\left(1-\frac{T_n}{T_l}\right)\right\}\quad\cdots\ (4)$$

Q: Stirring gas flow rate (Nm^3/min)
T_l: Molten steel temperature (K)
W_m: Molten steel weight (t)
ρ_1: Molten steel density (kg/m^3)
h: Molten metal surface height (m)
P_2: Atmospheric pressure (Torr)
η: Energy transfer efficiency (-)
T_n: Stirring gas temperature (K)

FIG. 1

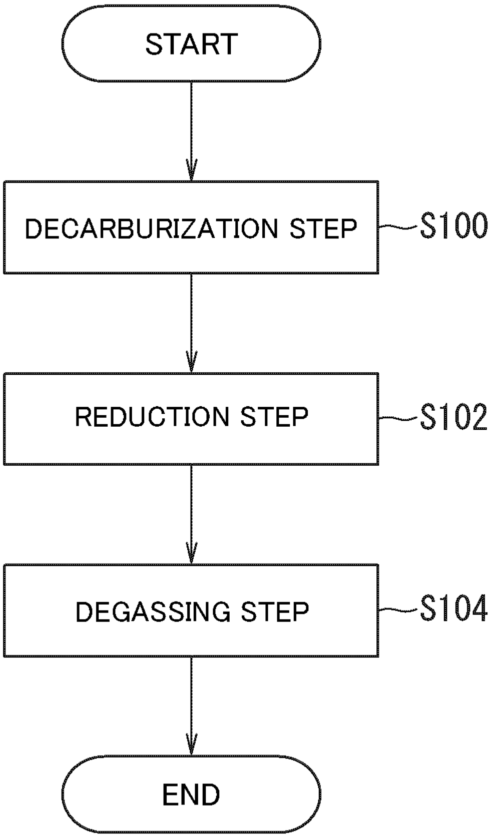

START
DECARBURIZATION STEP
S100
REDUCTION STEP
S102
DEGASSING STEP
S104
END

FIG. 2

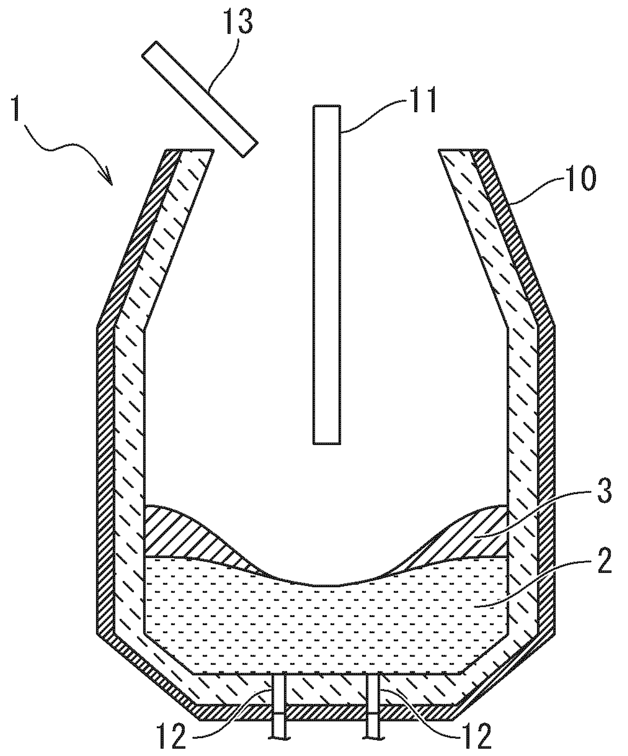
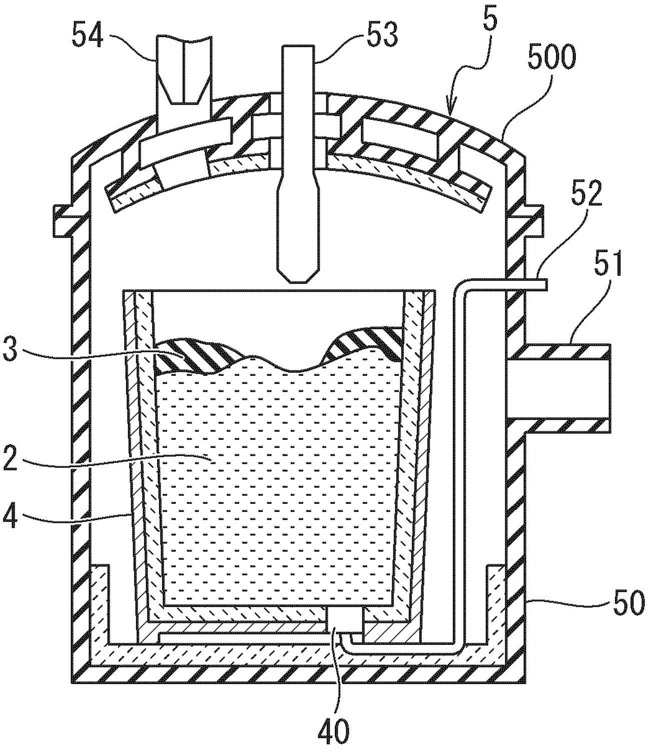


FIG. 3



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2018/019526

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl. C21C7/00(2006.01)i, C21C7/10(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)
Int.Cl. C21C7/00-C21C7/10, C21C5/28

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	1971-2018
Registered utility model specifications of Japan	1996-2018
Published registered utility model applications of Japan	1994-2018

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2016-188401 A (JFE STEEL CORPORATION) 04 November 2016, entire text, fig. 1-2 (Family: none)	1-2
A	JP 2008-101232 A (DAIDO STEEL CO., LTD.) 01 May 2008, entire text, fig. 1-4 (Family: none)	1-2
A	JP 1-225715 A (NKK CORP.) 08 September 1989, entire text, fig. 1-3 (Family: none)	1-2

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

* Special categories of cited documents:

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"&" document member of the same patent family

Date of the actual completion of the international search 06 July 2018 (06.07.2018)	Date of mailing of the international search report 17 July 2018 (17.07.2018)
Name and mailing address of the ISA/ Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Authorized officer Telephone No.

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REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 2013112855 A **[0007]**
- JP 4534734 B **[0007]**
- JP H05125428 B **[0007]**