



(11) **EP 4 497 839 A1**

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
29.01.2025 Bulletin 2025/05

(51) International Patent Classification (IPC):
C21C 7/00^(2006.01) C21C 7/10^(2006.01)

(21) Application number: **23803397.1**

(52) Cooperative Patent Classification (CPC):
C21C 7/00; C21C 7/10

(22) Date of filing: **21.04.2023**

(86) International application number:
PCT/JP2023/016018

(87) International publication number:
WO 2023/218915 (16.11.2023 Gazette 2023/46)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA
Designated Validation States:
KH MA MD TN

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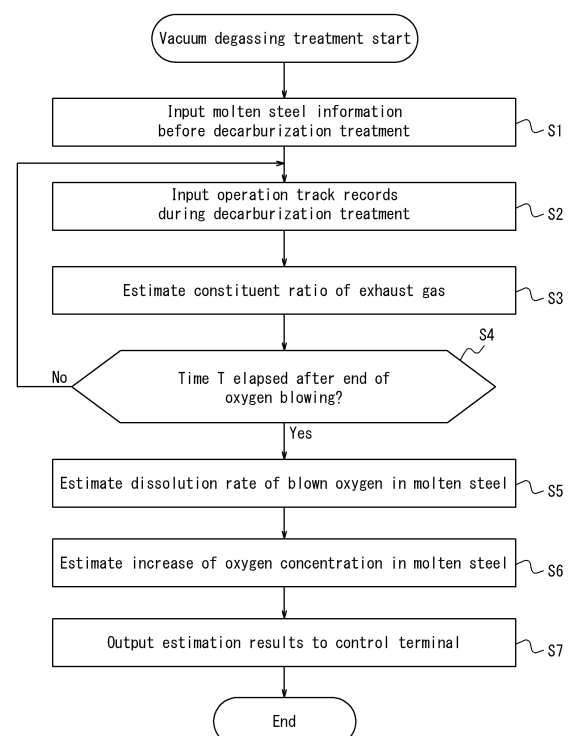
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(30) Priority: **09.05.2022 JP 2022077105**

(54) **STATE ESTIMATION METHOD FOR VACUUM DEGASIFICATION PROCESS, OPERATION METHOD, MOLTEN STEEL MANUFACTURING METHOD, AND STATE ESTIMATION DEVICE FOR VACUUM DEGASIFICATION PROCESS**

(57) Provided are a state estimation method for vacuum degassing treatment, etc. capable of highly accurate state estimation in vacuum degassing treatment. A state estimation method for vacuum degassing treatment includes: an input step (S1, S2) of receiving input of operation track records related to manipulated variables during vacuum degassing treatment and time-series exhaust gas measured values including a flow rate of exhaust gas discharged from a vacuum degassing line that performs the vacuum degassing treatment and component concentrations of CO gas, CO₂ gas, and O₂ gas contained in the exhaust gas, as input information; and a calculation step (S3) of, based on the input information, classifying sources of gases that constitute the exhaust gas into a plurality of sources including blown oxygen and air entering a vacuumized region in the vacuum degassing line before or during the treatment, and estimating a constituent ratio of the classified plurality of sources.

FIG. 2



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Description

TECHNICAL FIELD

- 5 **[0001]** The present disclosure relates to a state estimation method for vacuum degassing treatment, an operation method, a molten steel production method, and a state estimation device for vacuum degassing treatment.

BACKGROUND

- 10 **[0002]** When casting molten steel by continuous casting, it is necessary to keep the oxygen concentration in the molten steel at a very low value. In a typical steelmaking process, the oxygen concentration in the molten steel is decreased by adding a deoxidizer to the molten steel. When performing secondary refining using vacuum degassing treatment after converter treatment, on the other hand, oxygen is blown into the molten steel in order to increase the oxygen concentration in the molten steel in some cases. Oxygen blowing may be intended, for example, to promote decarburization for steel
- 15 types with a low target carbon concentration in the molten steel. By increasing the oxygen concentration in the molten steel, the reaction in which carbon in the molten steel reacts with oxygen in the molten steel to generate CO gas can be balanced with a lower carbon concentration in the molten steel. Oxygen blowing may be intended, for example, to adjust the temperature of the molten steel by utilizing the heat generated as a result of the reaction with the component elements in the molten steel. Here, the components in the molten steel that are reacted are not limited to components present in the molten steel at the time of oxygen blowing but also include components added after oxygen blowing. Especially in the case
- 20 where a deoxidizer is added after oxygen blowing, the increase in the temperature of the molten steel depends on the oxygen concentration in the molten steel. Hence, in order to control the components and temperature of the molten steel to the desired values by performing secondary refining, it is necessary to control the oxygen concentration in the molten steel to the desired value.

- 25 **[0003]** Here, oxygen blown in by oxygen blowing (hereafter referred to as "blown oxygen") does not fully dissolve in the molten steel and contribute to increasing the oxygen concentration in the molten steel. Part of the blown oxygen may react with CO gas in the gas phase to form CO₂ gas. Part of the blown oxygen may be exhausted to the outside of the system as O₂ gas. Therefore, in order to increase the oxygen concentration in the molten steel to the desired value by oxygen blowing, the proportion of blown oxygen dissolved in the molten steel needs to be estimated accurately.

- 30 **[0004]** Since blown oxygen either dissolves in the molten steel or is discharged from the exhaust system, determining the amount of oxygen discharged from the exhaust system using an exhaust gas measurement device makes it possible to estimate the dissolution rate of blown oxygen in the molten steel (i.e. the proportion of blown oxygen dissolved in the molten steel). However, the oxygen exhausted from the vacuum degassing line contains oxygen other than the oxygen blown in by oxygen blowing during vacuum degassing treatment, and such other oxygen needs to be subtracted. Examples of such
- 35 oxygen supply sources include the molten steel to be treated, air present in the vacuumized region before the start of the treatment, and air entering the vacuumized region from an insufficiently sealed part of the vacuum exhaust system during the treatment.

- [0005]** The amount of oxygen supplied from air can be determined by calculating the amount of N₂ gas contained in the exhaust gas. In the refining process, approximately the whole flow rate of the exhaust gas is occupied by components such
- 40 as CO gas, CO₂ gas, O₂ gas, inert gas blown in to stir the molten steel, and N₂ gas. The flow rates of CO gas, CO₂ gas, and O₂ gas are measured by an exhaust gas measurement device. The flow rate of inert gas is a manipulated variable for operation. Hence, the remainder obtained by subtracting the flow rates of these gases from the measured flow rate of the exhaust gas can be estimated to be the flow rate of N₂ gas.

- [0006]** For example, in JP 2019-183227 A (PTL 1), the amount of air entering an exhaust system during operation is estimated by the foregoing calculation method for the purpose of deriving converter parameters. In JP 6583594 B1 (PTL
- 45 2), estimation that takes into account the amount of entrained air is described as an embodiment of estimating the composition of molten metal in a refining process, and the amount of entrained air is estimated by the foregoing calculation method.

50 CITATION LIST

Patent Literature

[0007]

- 55 PTL 1: JP 2019-183227 A
PTL 2: JP 6583594 B1

SUMMARY

(Technical Problem)

[0008] The techniques described in PTL 1 and PTL 2 are both intended for a converter process. In the case of a converter, there is a large gap between the converter and the skirt and air enters from this gap, so that the flow rate of incoming air changes greatly with time. In a vacuum degassing line, on the other hand, the air pressure is kept very low in the exhaust system, and the flow rate of air entering from an insufficiently sealed part is considered to change little with time. Accordingly, the estimation methods proposed in PTL 1 and PTL 2 cannot be directly applied to vacuum degassing treatment.

[0009] Moreover, the ultimate purpose in PTL 1 is to derive converter parameters, and the ultimate purpose in PTL 2 is to estimate the carbon concentration in molten metal and the FeO concentration in slag. Thus, no method has been proposed that, for example, estimates the proportion of blown oxygen dissolved in molten steel and the oxygen concentration in molten steel in vacuum degassing treatment.

[0010] It could therefore be helpful to provide a state estimation method for vacuum degassing treatment, an operation method, a molten steel production method, and a state estimation device for vacuum degassing treatment that are capable of highly accurate state estimation in vacuum degassing treatment.

(Solution to Problem)

[0011]

(1) A state estimation method for vacuum degassing treatment according to an embodiment of the present disclosure includes: an input step of receiving input of operation track records related to manipulated variables during vacuum degassing treatment and time-series exhaust gas measured values including a flow rate of exhaust gas discharged from a vacuum degassing line that performs the vacuum degassing treatment and component concentrations of CO gas, CO₂ gas, and O₂ gas contained in the exhaust gas, as input information; and a calculation step of, based on the input information, classifying sources of gases that constitute the exhaust gas into a plurality of sources including blown oxygen and air entering a vacuumized region in the vacuum degassing line before start of the vacuum degassing treatment or during the vacuum degassing treatment, and estimating a constituent ratio of the classified plurality of sources.

(2) As an embodiment of the present disclosure, in (1), the calculation step includes estimating a proportion of N₂ gas in the exhaust gas from the input information and calculating a proportion of the air entering the vacuumized region based on the N₂ gas in the exhaust gas.

(3) As an embodiment of the present disclosure, in (1) or (2), the calculation step includes estimating a dissolution rate of the blown oxygen in molten steel based on the estimated constituent ratio in a case where at least a reference time has elapsed from an end time of oxygen blowing.

(4) As an embodiment of the present disclosure, in (3), the calculation step includes estimating an increase of an oxygen concentration in the molten steel based on the estimated dissolution rate.

(5) As an embodiment of the present disclosure, in (1) or (2), in the calculation step, the constituent ratio is estimated in a case where a flow rate of air in the exhaust gas is determined to be constant based on a degree of vacuum of the vacuumized region.

(6) An operation method according to an embodiment of the present disclosure operates a vacuum degassing line by executing the state estimation method for vacuum degassing treatment according to (1) or (2).

(7) A molten steel production method according to an embodiment of the present disclosure refines molten steel in a vacuum degassing line operated by the operation method according to (6) to produce refined molten steel.

(8) A state estimation device for vacuum degassing treatment according to an embodiment of the present disclosure includes: an operation information input unit configured to receive input of operation track records related to manipulated variables during vacuum degassing treatment and time-series exhaust gas measured values including a flow rate of exhaust gas discharged from a vacuum degassing line that performs the vacuum degassing treatment and component concentrations of CO gas, CO₂ gas, and O₂ gas contained in the exhaust gas, as input information; and an exhaust gas classification calculation unit configured to, based on the input information, classify sources of gases that constitute the exhaust gas into a plurality of sources including blown oxygen and air entering a vacuumized region in the vacuum degassing line before start of the vacuum degassing treatment or during the vacuum degassing treatment, and estimate a constituent ratio of the classified plurality of sources.

(9) As an embodiment of the present disclosure, in (8), the exhaust gas classification calculation unit is configured to estimate a proportion of N₂ gas in the exhaust gas from the input information and calculate a proportion of the air entering the vacuumized region based on the N₂ gas in the exhaust gas.

(10) As an embodiment of the present disclosure, in (8) or (9), a blown oxygen dissolution rate calculation unit configured to estimate a dissolution rate of the blown oxygen in molten steel based on the estimated constituent ratio in a case where at least a reference time has elapsed from an end time of oxygen blowing is included.

(11) As an embodiment of the present disclosure, in (10), an in-molten steel oxygen concentration increase calculation unit configured to estimate an increase of an oxygen concentration in the molten steel based on the estimated dissolution rate is included.

(12) As an embodiment of the present disclosure, in (8) or (9), the exhaust gas classification calculation unit is configured to estimate the constituent ratio in a case where a flow rate of air in the exhaust gas is determined to be constant based on a degree of vacuum of the vacuumized region.

(Advantageous Effect)

[0012] With the presently disclosed techniques, the sources of the gases that constitute the exhaust gas in vacuum degassing treatment are classified into a plurality of sources including blown oxygen and air entering the vacuumized region in the vacuum degassing line before the start of the vacuum degassing treatment or during the treatment, and the constituent ratio of the classified plurality of sources is estimated. It is thus possible to provide a state estimation method for vacuum degassing treatment, an operation method, a molten steel production method, and a state estimation device for vacuum degassing treatment that are capable of highly accurate state estimation in vacuum degassing treatment.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] In the accompanying drawings:

FIG. 1 is a schematic diagram illustrating the structure of a state estimation device for vacuum degassing treatment according to an embodiment of the present disclosure;

FIG. 2 is a flowchart illustrating a process executed by the state estimation device;

FIG. 3 illustrates time-series calculation results of the exhaust gas constituent ratio in a vacuum degassing treatment charge to which an embodiment of the present disclosure is applied; and

FIG. 4 illustrates time-series measurement and calculation results of the flow rate of blown oxygen, the flow rate of blown oxygen in exhaust gas, and the degree of vacuum of the vacuum vessel in a vacuum degassing treatment charge to which an embodiment of the present disclosure is applied.

DETAILED DESCRIPTION

[0014] A state estimation device and state estimation method for vacuum degassing treatment according to an embodiment of the present disclosure will be described below, with reference to the drawings. Although this embodiment describes an example in which the vacuum degassing treatment is RH vacuum degassing treatment performed using an RH vacuum degassing line, the vacuum degassing treatment is not limited to RH vacuum degassing treatment. The below-described state estimation method can also be applied, for example, to vacuum degassing treatment performed using a line that includes a vacuum vessel and only one immersion tube that is immersed in a ladle and sucks up molten steel into the vacuum vessel or a line (apparatus) that includes no vacuum vessel and creates a vacuum state on the surface of molten steel in a ladle.

[Structure]

[0015] FIG. 1 is a schematic diagram illustrating the structure of a state estimation device 20 and a vacuum degassing line 100 according to this embodiment. The state estimation device 20 estimates, for example, the internal state of the vacuum degassing line 100 during vacuum degassing treatment in the vacuum degassing line 100. In this embodiment, the vacuum degassing line 100 is operated by the state estimation device 20 executing the below-described state estimation method for vacuum degassing treatment. That is, state estimation for vacuum degassing treatment is executed as an operation method for the vacuum degassing line 100. In this embodiment, the vacuum degassing line 100 forms part of a molten steel production line. A molten steel production method is executed in the molten steel production line. The molten steel production method includes refining molten steel in the vacuum degassing line 100 to produce refined molten steel.

[0016] The RH vacuum degassing line 100 includes a vacuum vessel 101 and a ladle 102 that are connected to each other by two immersion tubes 103. The vacuum vessel 101 is connected to an exhaust duct 104. The gas inside the vacuum vessel 101 is exhausted through the exhaust duct to reduce the pressure in the vacuum vessel 101 and suck up the molten steel in the ladle 102. Then, inert gas is blown in through a pipe 105 from one of the immersion tubes 103 to

circulate the molten steel between the vacuum vessel 101 and the ladle 102. Oxygen is blown in from a blowing lance 106 installed in the vacuum vessel 101. Thus, oxygen can be supplied to the molten steel. The vacuum vessel 101 is an example of a vacuumized region, i.e. a region depressurized to create a vacuum, in the vacuum degassing line 100. The vacuumized region in the vacuum degassing line 100 also includes the exhaust duct 104 connected to the vacuum vessel 101.

[0017] An exhaust gas flowmeter 107 and an exhaust gas component concentration meter 108 are installed inside the exhaust duct 104. The exhaust gas flowmeter 107 measures the flow rate of the exhaust gas. The exhaust gas component concentration meter 108 measures the concentrations of the components in the exhaust gas, including CO gas, CO₂ gas, and O₂ gas.

[0018] A vacuum degassing treatment control system to which the state estimation device 20 for vacuum degassing treatment is applied includes a control device 10 and the state estimation device 20 for vacuum degassing treatment as main components. The control device 10 is composed of an information processing device such as a computer, and controls operation-related manipulated variables, such as the exhaust volume of the exhaust line, the flow rate of inert gas for circulation, and the flow rate of blown oxygen, so that the component concentrations and temperature of the molten steel will fall within the target ranges after vacuum degassing treatment from the track records before the vacuum degassing treatment. The control device 10 also collects operation track record data such as the degree of vacuum in the vacuum vessel 101, the flow rate of inert gas for circulation, the flow rate of blown oxygen, the flow rate of exhaust gas, and the component concentrations of exhaust gas, and outputs the data to the state estimation device 20.

[0019] As illustrated in FIG. 1, the state estimation device 20 includes an operation information input unit 21, a calculation unit, and an output unit 25. The calculation unit is a functional unit that executes calculations to estimate the state of vacuum degassing treatment. In this embodiment, the calculation unit includes an exhaust gas classification calculation unit 22, a blown oxygen dissolution rate calculation unit 23, and an in-molten steel oxygen concentration increase calculation unit 24.

[0020] The operation information input unit 21 receives input of operation track records related to manipulated variables during vacuum degassing treatment and time-series exhaust gas measured values including the flow rate of exhaust gas discharged from the vacuum degassing line 100 that performs the vacuum degassing treatment and the component concentrations of CO gas, CO₂ gas, and O₂ gas contained in the exhaust gas, as input information.

[0021] The exhaust gas classification calculation unit 22 classifies the sources of the gases that constitute the exhaust gas discharged from the vacuum degassing line 100 into a plurality of sources and estimates the constituent ratio of the classified plurality of sources, based on the input information acquired by the operation information input unit 21. The plurality of sources include blown oxygen and air entering the vacuumized region in the vacuum degassing line 100 before the start of the vacuum degassing treatment or during the treatment. The exhaust gas classification calculation unit 22 may estimate the proportion of N₂ gas in the exhaust gas from the input information, and calculate the proportion of the air entering the vacuumized region based on the N₂ gas in the exhaust gas.

[0022] The blown oxygen dissolution rate calculation unit 23 estimates the dissolution rate of the blown oxygen in the molten steel based on the constituent ratio of the plurality of sources estimated by the exhaust gas classification calculation unit 22.

[0023] The in-molten steel oxygen concentration increase calculation unit 24 estimates the increase of the oxygen concentration in the molten steel based on the dissolution rate estimated by the blown oxygen dissolution rate calculation unit 23.

[0024] The output unit 25 outputs the results of the calculations performed by the calculation unit to estimate the state of the vacuum degassing treatment, to the control device 10. The control device 10 may control the operation-related manipulated variables based on the calculation results obtained from the output section 25.

[0025] The state estimation device 20 for vacuum degassing treatment is composed of an information processing device such as a computer. The state estimation device 20 for vacuum degassing treatment functions as the operation information input unit 21, the exhaust gas classification calculation unit 22, the blown oxygen dissolution rate calculation unit 23, the in-molten steel oxygen concentration increase calculation unit 24, and the output unit 25 by a processor such as a central processing unit (CPU) in the information processing device executing a computer program.

[0026] The state estimation device 20 for vacuum degassing treatment having the foregoing structure performs the below-described state estimation process for vacuum degassing treatment to classify the gases that constitute the exhaust gas and estimate the constituent ratio. For a charge in which oxygen blowing is performed during treatment, the dissolution rate of the blown oxygen in the molten steel is estimated from the estimated exhaust gas constituent ratio. The estimation result can then be used to estimate the increase of the oxygen concentration in the molten steel due to the blown oxygen with high accuracy. The operation of the state estimation device 20 for vacuum degassing treatment will be described below, with reference to the flowchart in FIG. 2. The following description assumes that oxygen blowing is performed during vacuum degassing treatment.

[0027] FIG. 2 is a flowchart illustrating the state estimation process for vacuum degassing treatment according to an embodiment of the present disclosure. When an instruction to execute vacuum degassing treatment is input, the flowchart

in FIG. 2 starts and the state estimation process proceeds to step S1.

[0028] In step S1, the operation information input unit 21 acquires molten steel information before the start of the decarburization treatment. The molten steel information may include, for example, the weight of the molten steel and the measurement and analysis results obtained by component analysis. This completes step S1, and the state estimation process proceeds to step S2.

[0029] In step S2, the operation information input unit 21 acquires operation track records related to manipulated variables during vacuum degassing treatment. Items necessary for the calculations in the exhaust gas classification calculation unit 22, blown oxygen dissolution rate calculation unit 23, and in-molten steel oxygen concentration increase calculation unit 24 are acquired as the operation track records. For example, the operation information input unit 21 acquires the degree of vacuum in the vacuum vessel 101, the flow rate of inert gas for circulation, and the flow rate of blown oxygen as the operation track records. In this embodiment, the operation information input unit 21 also acquires, as input information, time-series exhaust gas measured values including the flow rate of exhaust gas and the component concentrations of CO gas, CO₂ gas, and O₂ gas contained in the exhaust gas, together with the operation track records. This completes step S2, and the state estimation process proceeds to step S3. Steps S1 and S2 correspond to the input step.

[Exhaust gas classification calculation process]

[0030] In step S3, the exhaust gas classification calculation unit 22 classifies the gases that constitute the exhaust gas discharged during the vacuum degassing treatment and estimates the constituent ratio.

[0031] In RH vacuum degassing treatment, the supply sources of exhaust gas are classified into the following five types: impurity components contained in molten steel and removed as gas by depressurization, inert gas for circulation, air present in the vacuum vessel 101 before the start of vacuum degassing treatment, leakage air entering the vacuumized region (the vacuum vessel 101 and the exhaust duct 104) during the vacuum degassing treatment, and blown oxygen.

[0032] The main impurity components contained in the molten steel are hydrogen, nitrogen, and carbon. In most steel types, the amount of impurity components other than carbon is small enough to be negligible. Since carbon is removed from the molten steel as CO gas, its discharge amount can be obtained by exhaust gas measurement. The inert gas for circulation is an operation-related manipulated variable, and therefore its amount can be obtained.

[0033] The air present in the vacuum vessel 101 before the start of vacuum degassing treatment and the leakage air entering the vacuumized region during the treatment can be distinguished by calculating the amount of N₂ contained in the exhaust gas. Approximately the whole flow rate of the exhaust gas is occupied by CO gas, CO₂ gas, O₂ gas, inert gas blown in to stir the molten steel, and N₂ gas as components of the exhaust gas. The exhaust volumes of components other than N₂ gas can be calculated from exhaust gas measurement results or operation control track records. Assuming an unknown component of the exhaust gas as N₂ gas, its amount can be calculated using the following formula (1).

[Math. 1]

$$f_{N_2} = f_g \left(1 - \frac{r_{CO} + r_{CO_2} + r_{O_2}}{100} \right) - f_{Circ} \quad \dots \text{formula (1).}$$

[0034] Here, f_{N_2} is the N₂ flow rate [Nm³/h] in the exhaust gas. f_g is the flow rate of the exhaust gas [Nm³/h]. r_{CO} is the CO concentration [vol%] in the exhaust gas. r_{CO_2} is the CO₂ concentration [vol%] in the exhaust gas. r_{O_2} is the O₂ concentration [vol%] in the exhaust gas. f_{Circ} is the flow rate of Ar gas blown in for circulation [Nm³/h]. In the case where the measurement results of the flow rate and component concentrations of the exhaust gas contain known errors, it is preferable that the exhaust gas classification calculation unit 22 removes or reduces the known errors before performing the calculation of formula (1). The known errors are assumed to be, for example, errors such as offsets contained in measured values. If the time taken for the inert gas for circulation to reach the exhaust gas flowmeter is known, it is desirable to use f_{Circ} reflecting this time delay in the calculation of formula (1).

[0035] In the case where the N₂ flow rate in the exhaust gas is calculated by formula (1), the air flow rate f_a [Nm³/h] in the exhaust gas can be calculated from the nitrogen abundance ratio in air according to the following formula (2).

[Math. 2]

$$f_a = \frac{100}{79} f_{N_2} \quad \dots \text{formula (2).}$$

[0036] Based on track record data of vacuum degassing treatment, I found that, when the vacuum vessel 101 is

evacuated to near the ultimate vacuum (target degree of vacuum) in vacuum degassing treatment, the flow rate of air in the exhaust gas calculated by the foregoing formula (2) is approximately constant. Since the degree of vacuum changes little near the ultimate vacuum, the entire amount of air in the exhaust gas can be assumed to derive from leakage during the treatment. Moreover, the flow rate of leakage air is constant if the air pressure in the vacuum vessel 101 is sufficiently low. It is therefore reasonable that the flow rate of air in the exhaust gas is approximately constant.

[0037] As described above, the constituent ratio of the four supply sources other than blown oxygen from among the five supply sources constituting the exhaust gas can be quantitatively estimated. The remainder (balance) can then be estimated as exhaust gas that derives from blown oxygen. The constituent ratio of all of the plurality of sources is thus estimated. This completes step S3, and the state estimation process proceeds to step S4.

[Blown oxygen dissolution rate calculation process]

[0038] In step S4, whether the time elapsed from the oxygen blowing end time to the time at which the exhaust gas constituent ratio estimation is performed is longer than or equal to a predetermined reference time T is determined. If the elapsed time after the oxygen blowing is shorter than the reference time, the state estimation process returns to step S2 to repeat from step S2 onward. If the elapsed time is longer than the reference time, the state estimation process proceeds to step S5. The reason for performing such a conditional branching process will be explained in the description of step S5.

[0039] In step S5, the blown oxygen dissolution rate calculation unit 23 estimates the proportion of blown oxygen dissolved in the molten steel.

[0040] First, the amount of oxygen in the exhaust gas can be calculated using the following formula (3).
[Math. 3]

$$f_{O_2} = f_g \cdot \frac{0.5r_{CO} + r_{CO_2} + r_{O_2}}{100} \quad \dots \text{formula (3)}.$$

[0041] Here, the amount of oxygen in the exhaust gas is evaluated in terms of O_2 volumetric flow rate. f_{O_2} is the O_2 flow rate [Nm^3/h] in the exhaust gas. In the following, the amount of oxygen in the exhaust gas is equally evaluated in terms of O_2 volumetric flow rate.

[0042] Of the amount of oxygen in the exhaust gas, the flow rate $f_{O_2,dec}$ [Nm^3/h] of oxygen derived from decarburization can be calculated using the following formula (4) because it is all supplied to the vacuum vessel 101 as CO.
[Math. 4]

$$f_{O_2,dec} = f_g \cdot \frac{0.5(r_{CO} + r_{CO_2})}{100} \quad \dots \text{formula (4)}.$$

[0043] Of the amount of oxygen in the exhaust gas, the flow rate $f_{O_2,a}$ [Nm^3/h] of oxygen derived from incoming air can be calculated from the oxygen abundance ratio in air using the following formula (5).
[Math. 5]

$$f_{O_2,a} = \frac{21}{100} f_a \quad \dots \text{formula (5)}.$$

[0044] The only other supply source of oxygen to the exhaust gas is blown oxygen. Hence, of the amount of oxygen in the exhaust gas, the flow rate $f_{O_2,b}$ [Nm^3/h] of oxygen derived from oxygen blowing can be calculated using the following formula (6).
[Math. 6]

$$f_{O_2,b} = f_{O_2} - (f_{O_2,dec} + f_{O_2,a}) \quad \dots \text{formula (6)}.$$

[0045] Based on track record data of vacuum degassing treatment, I obtained three findings about the temporal changes

of $f_{O_2,b}$. Firstly, there is a time delay from the start of oxygen blowing until $f_{O_2,b}$ increases. Secondly, after the end of oxygen blowing, $f_{O_2,b}$ rapidly converges to 0 after a certain time delay. Thirdly, the time from when the blown oxygen not dissolved in the molten steel is blown into the molten steel to when it is observed by the exhaust gas measurement device cannot be considered constant. The third finding means that the temporal change pattern of $f_{O_2,b}$ cannot be regarded as the same as the oxygen blowing pattern and it is difficult to continuously estimate the dissolution rate of blown oxygen. The difference in pattern is considered to be because, while part of blown oxygen reacts with CO gas released into the vacuum vessel 101 to form CO₂ gas, the time from when oxygen is blown in to when it reaches the exhaust gas measurement device varies depending on the time required for this reaction.

[0046] From these findings, the reference time T for $f_{O_2,b}$ to reliably converge to 0 after the end of oxygen blowing is set, and the oxygen dissolution rate x of blown oxygen is estimated using the following formula (7). For example, the time T can be determined in the following manner: A threshold is set for $f_{O_2,b}$, and the time difference between the time when $f_{O_2,b}$ falls below the threshold and the oxygen blowing end time is calculated for each of a plurality of charges. The maximum time difference is then set as the time T.

[Math. 7]

$$x = 1 - \frac{\int_{t_0}^{t_1} f_{O_2,b} dt}{Q_{O_2}}$$

... formula (7).

[0047] Here, t_0 is the oxygen blowing start time or the time obtained by adding the time T to the oxygen blowing start time. t_1 is the time obtained by adding the time T to the oxygen blowing end time. Q_{O_2} is the total amount of blown oxygen [Nm³].

[0048] For accurate estimated calculation of the oxygen dissolution rate x using formula (7), the conditional branching process is performed in step S4.

[0049] As a result of this calculation process, step S5 ends and the state estimation process proceeds to step S6.

[0050] [In-molten steel oxygen concentration increase calculation process]

[0051] In step S6, the in-molten steel oxygen concentration increase calculation unit 24 estimates the increase of the oxygen concentration in the molten steel.

[0052] The in-molten steel oxygen concentration increase calculation unit 24 can calculate the increase $\Delta[O]$ [ppm] of the oxygen concentration in the molten steel due to oxygen blowing from the oxygen dissolution rate x of blown oxygen estimated in step S5 using the following formula (8).

[Math. 8]

$$\Delta[O] = \frac{x Q_{O_2} \rho_{O_2}}{W} \cdot 10^6$$

... formula (8).

[0053] Here, ρ_{O_2} is the oxygen density [kg/Nm³]. W is the weight of the molten steel [kg].

[0054] As a result of this calculation process, step S6 ends and the state estimation process proceeds to step S7. Steps S3 to S6 correspond to the calculation step.

[0055] In step S7, the various information estimated in the foregoing processes, particularly the dissolution rate of the blown oxygen in the molten steel and the increase of the oxygen concentration in the molten steel, are output to the control device 10.

[0056] As described above, the state estimation method for vacuum degassing treatment, operation method, molten steel production method, and state estimation device 20 for vacuum degassing treatment according to this embodiment with the above-described structure and processes classify the sources of the gases that constitute exhaust gas in vacuum degassing treatment into a plurality of sources, and estimate the constituent ratio of the classified plurality of sources. This enables highly accurate state estimation in vacuum degassing treatment.

[0057] Moreover, the dissolution rate of the blown oxygen in the molten steel and the increase of the oxygen concentration in the molten steel can be estimated based on the result of the state estimation. The estimated increase of the oxygen concentration in the molten steel is used to estimate the oxygen concentration in the molten steel, so that the oxygen concentration in the molten steel is estimated with high accuracy. Based on the estimated oxygen concentration in the molten steel, it is possible to end decarburization treatment at appropriate timing and determine whether additional oxygen blowing is necessary in order to control the temperature of the molten steel to the desired value. A vacuum degassing line operation method and molten steel production method that enable highly accurate adjustment of the components and temperature of molten steel can thus be provided.

EXAMPLES

[0058] The effects according to the present disclosure will be described in detail below by way of examples, although the present disclosure is not limited to such examples.

[0059] In this example, for three charges of vacuum degassing treatment involving oxygen blowing using an RH vacuum degassing line, the constituent ratio of the exhaust gas was continuously estimated and the dissolution rate of blown oxygen and the increase of the oxygen concentration in the molten steel were estimated.

[0060] FIG. 3 is a stacked graph of the flow rate of the exhaust gas, illustrating the temporal changes of the constituent ratio of the exhaust gas after the start of oxygen blowing. FIG. 4 illustrates the temporal changes of the flow rate of blown oxygen, the flow rate of blown oxygen in the exhaust gas (i.e. the flow rate of oxygen undissolved in the molten steel), and the degree of vacuum of the vacuum vessel 101. In the latter half of the vacuum degassing treatment when evacuation of the vacuum vessel 101 progressed and the vacuum vessel 101 was evacuated to near the ultimate vacuum, the flow rate of air in the exhaust gas was approximately constant. Therefore, the exhaust gas classification calculation process by the exhaust gas classification calculation unit 22 is preferably performed in the case where the degree of vacuum reaches less than or equal to a threshold so that the flow rate of air in the exhaust gas will be stable. In other words, the exhaust gas classification calculation process is preferably performed in the case where it is determined that the flow rate of air in the exhaust gas is constant based on the degree of vacuum in the vacuumized region. The threshold may be determined based on the ultimate vacuum or past track record data.

[0061] As can be seen from FIG. 4, the amount of blown oxygen in the exhaust gas increased with a delay after the start of oxygen blowing, and rapidly converged to 0 with a delay after the end of oxygen blowing. Thus, the temporal changes of the amount of blown oxygen in the exhaust gas differ greatly in pattern from those of blown oxygen, indicating that it is difficult to continuously estimate the oxygen dissolution rate.

[0062] Table 1 shows the estimated oxygen dissolution rate and increase of the oxygen concentration in the molten steel due to blown oxygen, and the track records of the increase of the oxygen concentration in the molten steel. The track records of the increase of the oxygen concentration in the molten steel were calculated using the measured values of the carbon concentration and oxygen concentration in the molten steel before and during the vacuum degassing treatment. Since no deoxidizer was added, the reaction between oxygen and the metal components in the molten steel can be ignored. As shown in Table 1, the increase of the oxygen concentration in the molten steel estimated by the method according to the foregoing embodiment agreed well with the track record. This demonstrates that the method according to the foregoing embodiment is effective for estimating the oxygen dissolution rate of blown oxygen and the increase of the oxygen concentration in the molten steel due to blown oxygen with high accuracy.

[Table 1]

[0063]

(Table 1)

Verification charge	Oxygen dissolution rate (Estimated value)	Increase of oxygen concentration due to blown oxygen	
		Estimated value [ppm]	Track record [ppm]
A	0.60	98	96
B	0.73	252	252
C	0.62	105	104

[0064] Although the embodiment of the present disclosure has been described by way of the drawings and examples, various changes and modifications may be easily made by those of ordinary skill in the art based on the present disclosure. Such various changes and modifications are therefore included in the scope of the present disclosure. For example, the functions included in the components, steps, etc. may be rearranged without logical inconsistency, and a plurality of components, steps, etc. may be combined into one component, step, etc. and a component, step, etc. may be divided into a plurality of components, steps, etc. The embodiment of the present disclosure may also be implemented as a storage medium storing a program executed by a processor included in the device. These are also encompassed within the scope of the present disclosure.

REFERENCE SIGNS LIST

[0065]

10	control device
20	state estimation device
21	operation information input unit
22	exhaust gas classification calculation unit
5 23	blown oxygen dissolution rate calculation unit
24	in-molten steel oxygen concentration increase calculation unit
25	output unit
100	vacuum degassing line
101	vacuum vessel
10 102	ladle
103	immersion tube
104	exhaust duct
105	pipe
106	blowing lance
15 107	exhaust gas flowmeter
108	exhaust gas component concentration meter

Claims

- 20 1. A state estimation method for vacuum degassing treatment, comprising:

an input step of receiving input of operation track records related to manipulated variables during vacuum degassing treatment and time-series exhaust gas measured values including a flow rate of exhaust gas discharged from a vacuum degassing line that performs the vacuum degassing treatment and component concentrations of CO gas, CO₂ gas, and O₂ gas contained in the exhaust gas, as input information; and

a calculation step of, based on the input information, classifying sources of gases that constitute the exhaust gas into a plurality of sources including blown oxygen and air entering a vacuumized region in the vacuum degassing line before start of the vacuum degassing treatment or during the vacuum degassing treatment, and estimating a constituent ratio of the classified plurality of sources.
- 30 2. The state estimation method for vacuum degassing treatment according to claim 1, wherein the calculation step includes estimating a proportion of N₂ gas in the exhaust gas from the input information and calculating a proportion of the air entering the vacuumized region based on the N₂ gas in the exhaust gas.
- 35 3. The state estimation method for vacuum degassing treatment according to claim 1 or 2, wherein the calculation step includes estimating a dissolution rate of the blown oxygen in molten steel based on the estimated constituent ratio in a case where at least a reference time has elapsed from an end time of oxygen blowing.
- 40 4. The state estimation method for vacuum degassing treatment according to claim 3, wherein the calculation step includes estimating an increase of an oxygen concentration in the molten steel based on the estimated dissolution rate.
- 45 5. The state estimation method for vacuum degassing treatment according to claim 1 or 2, wherein in the calculation step, the constituent ratio is estimated in a case where a flow rate of air in the exhaust gas is determined to be constant based on a degree of vacuum of the vacuumized region.
- 50 6. An operation method of operating a vacuum degassing line by executing the state estimation method for vacuum degassing treatment according to claim 1 or 2.
7. A molten steel production method of refining molten steel in a vacuum degassing line operated by the operation method according to claim 6 to produce refined molten steel.
- 55 8. A state estimation device for vacuum degassing treatment, comprising:

an operation information input unit configured to receive input of operation track records related to manipulated variables during vacuum degassing treatment and time-series exhaust gas measured values including a flow rate of exhaust gas discharged from a vacuum degassing line that performs the vacuum degassing treatment and component concentrations of CO gas, CO₂ gas, and O₂ gas contained in the exhaust gas, as input information;

and

an exhaust gas classification calculation unit configured to, based on the input information, classify sources of gases that constitute the exhaust gas into a plurality of sources including blown oxygen and air entering a vacuumized region in the vacuum degassing line before start of the vacuum degassing treatment or during the vacuum degassing treatment, and estimate a constituent ratio of the classified plurality of sources.

9. The state estimation device for vacuum degassing treatment according to claim 8, wherein the exhaust gas classification calculation unit is configured to estimate a proportion of N_2 gas in the exhaust gas from the input information and calculate a proportion of the air entering the vacuumized region based on the N_2 gas in the exhaust gas.
10. The state estimation device for vacuum degassing treatment according to claim 8 or 9, comprising a blown oxygen dissolution rate calculation unit configured to estimate a dissolution rate of the blown oxygen in molten steel based on the estimated constituent ratio in a case where at least a reference time has elapsed from an end time of oxygen blowing.
11. The state estimation device for vacuum degassing treatment according to claim 10, comprising an in-molten steel oxygen concentration increase calculation unit configured to estimate an increase of an oxygen concentration in the molten steel based on the estimated dissolution rate.
12. The state estimation device for vacuum degassing treatment according to claim 8 or 9, wherein the exhaust gas classification calculation unit is configured to estimate the constituent ratio in a case where a flow rate of air in the exhaust gas is determined to be constant based on a degree of vacuum of the vacuumized region.

FIG. 1

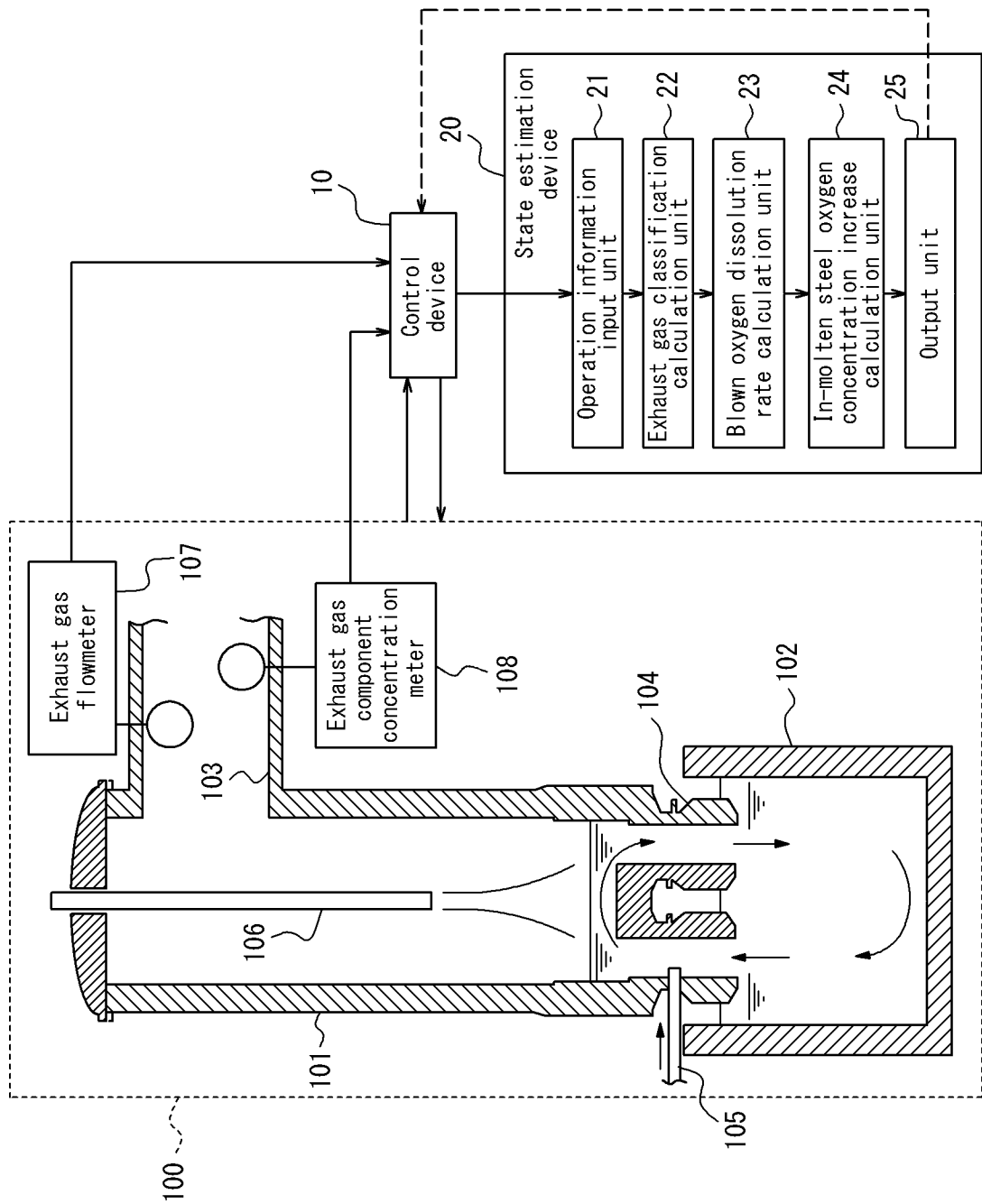


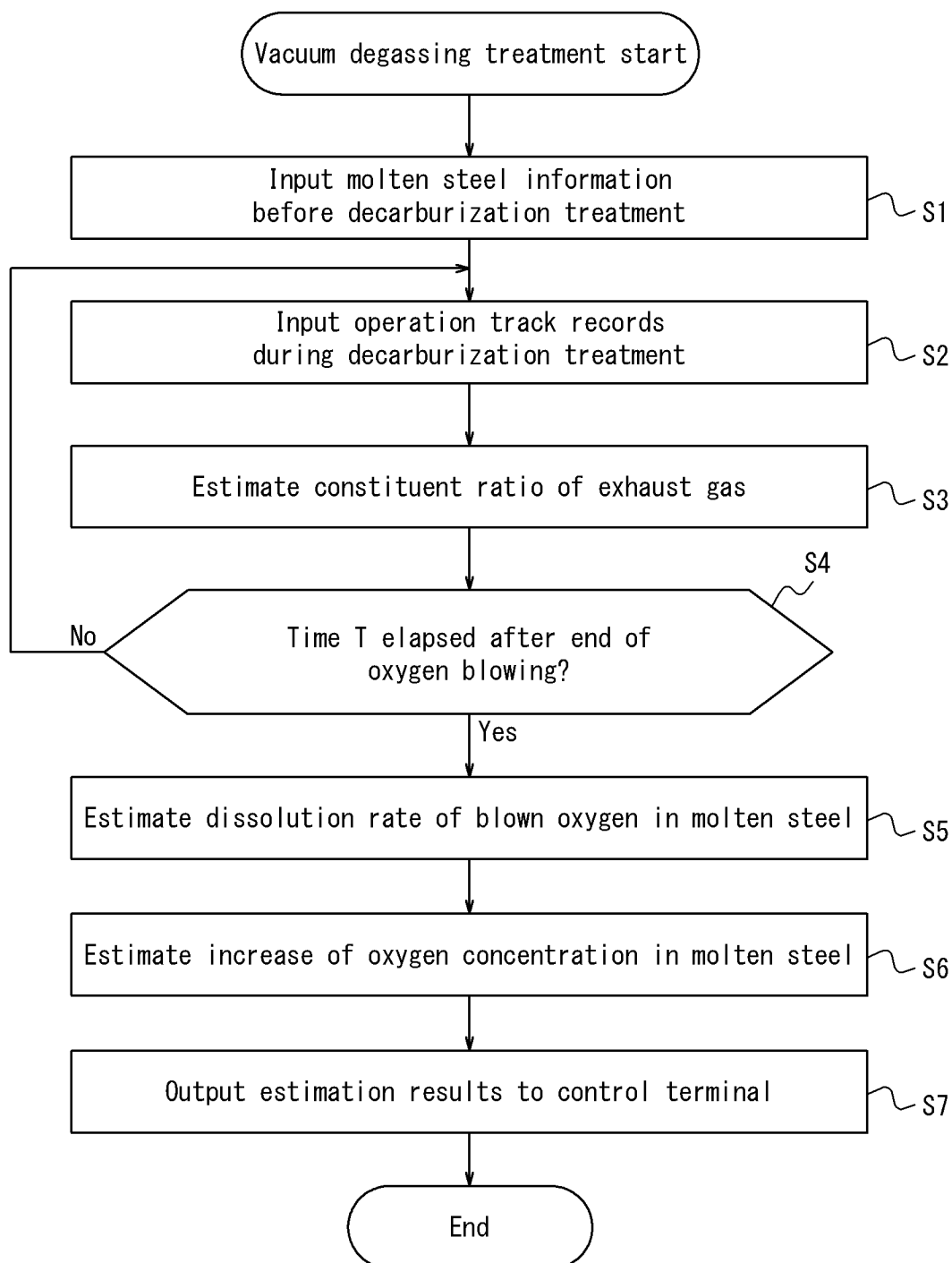
FIG. 2

FIG. 3

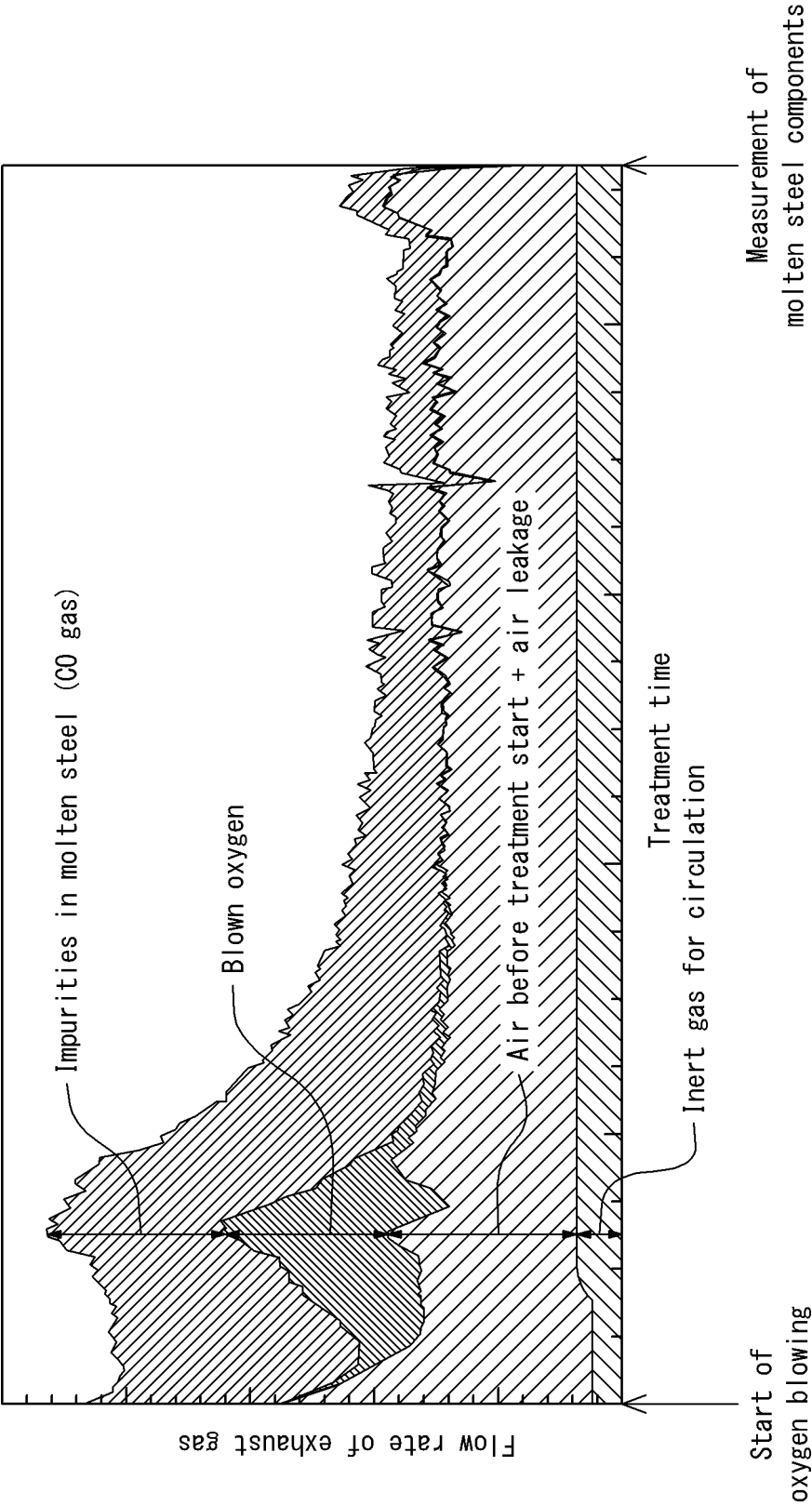
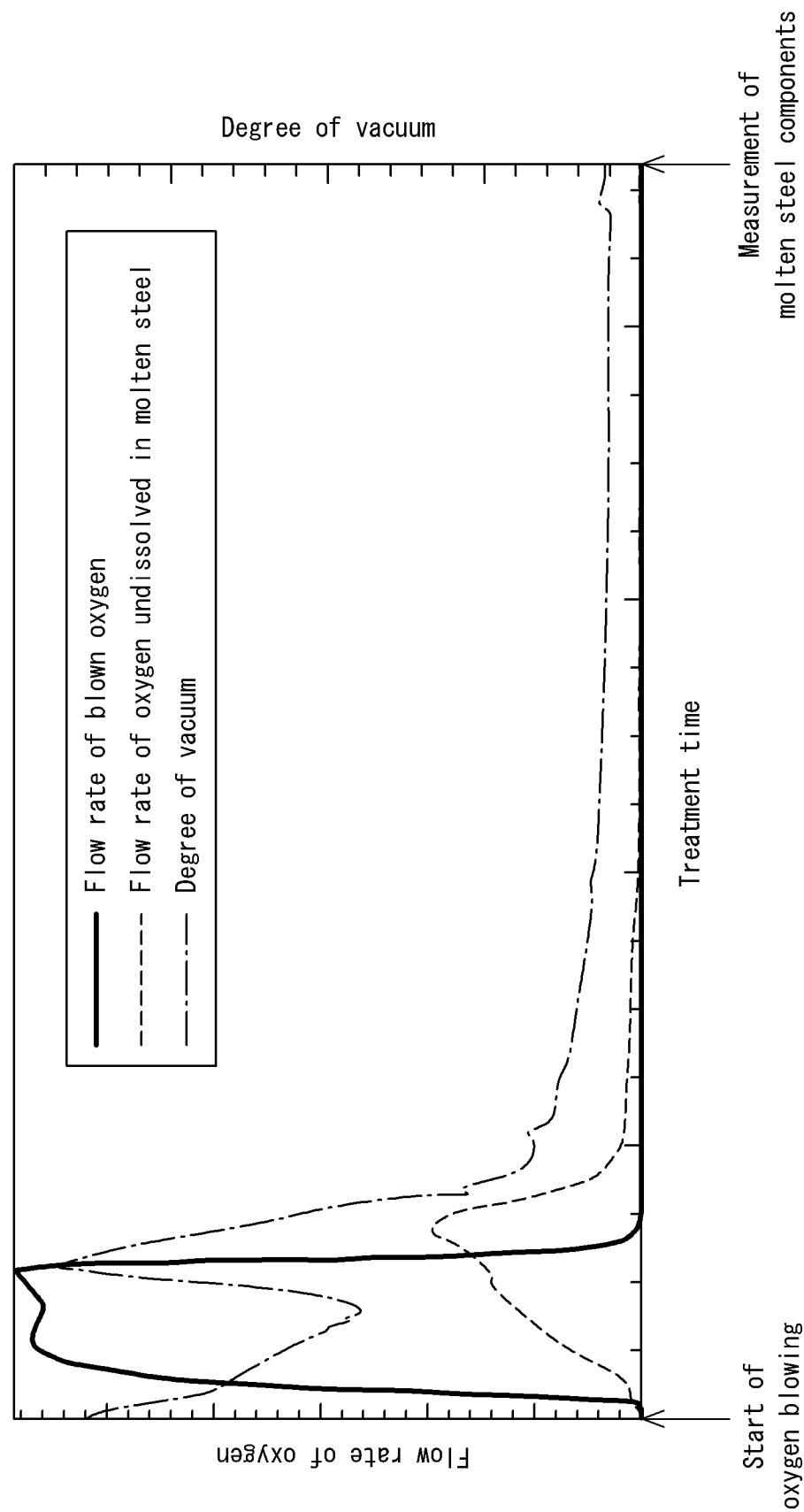


FIG. 4



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2023/016018

A. CLASSIFICATION OF SUBJECT MATTER

C21C 7/00(2006.01)i; **C21C 7/10**(2006.01)i
FI: C21C7/00 R; C21C7/10 A; C21C7/10 P

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)

C21C7/00; C21C7/10

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.
A	JP 08-260030 A (NISSHIN STEEL CO., LTD.) 08 October 1996 (1996-10-08) paragraphs [0007], [0016], fig. 5, 6	1-12
A	JP 2013-112835 A (NIPPON STEEL & SUMITOMO METAL CORP.) 10 June 2013 (2013-06-10) paragraph [0011]	1-12
A	JP 03-134114 A (SUMITOMO METAL INDUSTRIES, LTD.) 07 June 1991 (1991-06-07) claim 1	1-12
A	JP 2001-140012 A (NIPPON STEEL CORP.) 22 May 2001 (2001-05-22) claim 1	1-12
A	WO 2019/181562 A1 (JFE STEEL CORP.) 26 September 2019 (2019-09-26) claim 1	1-12

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

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

12 June 2023

Date of mailing of the international search report

27 June 2023

Name and mailing address of the ISA/JP

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2023/016018

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP	08-260030	A	08 October 1996	(Family: none)	
JP	2013-112835	A	10 June 2013	(Family: none)	
JP	03-134114	A	07 June 1991	(Family: none)	
JP	2001-140012	A	22 May 2001	(Family: none)	
WO	2019/181562	A1	26 September 2019	EP 3770279 A1 claim 1	

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

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2019183227 A [0006] [0007]
- JP 6583594 B [0006] [0007]