



(11)

EP 4 538 396 A1

(12)

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

(43) Date of publication:
16.04.2025 Bulletin 2025/16

(51) International Patent Classification (IPC):
C21C 5/28 ^(2006.01) **C21C 5/30** ^(2006.01)
C22B 9/16 ^(2006.01)

(21) Application number: **23842715.7**

(52) Cooperative Patent Classification (CPC):
C21C 5/28; C21C 5/30; C22B 9/16

(22) Date of filing: **14.06.2023**

(86) International application number:
PCT/JP2023/021995

(87) International publication number:
WO 2024/018783 (25.01.2024 Gazette 2024/04)

(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

- **YOKOMORI, Rei**
Tokyo 100-0011 (JP)
- **OGASAWARA, Futoshi**
Tokyo 100-0011 (JP)
- **KAWABATA, Ryo**
Tokyo 100-0011 (JP)
- **KIKUCHI, Naoki**
Tokyo 100-0011 (JP)

(30) Priority: **19.07.2022 JP 2022114590**

(74) Representative: **Hoffmann Eitle**
Patent- und Rechtsanwälte PartmbB
Arabellastraße 30
81925 München (DE)

(71) Applicant: **JFE Steel Corporation**
Tokyo 100-0011 (JP)

(72) Inventors:
• **HATTORI, Yudai**
Tokyo 100-0011 (JP)

(54) **COLD IRON SOURCE SOLUBILITY ESTIMATION DEVICE, COLD IRON SOURCE SOLUBILITY ESTIMATION METHOD, AND REFINING TREATMENT METHOD FOR MOLTEN IRON**

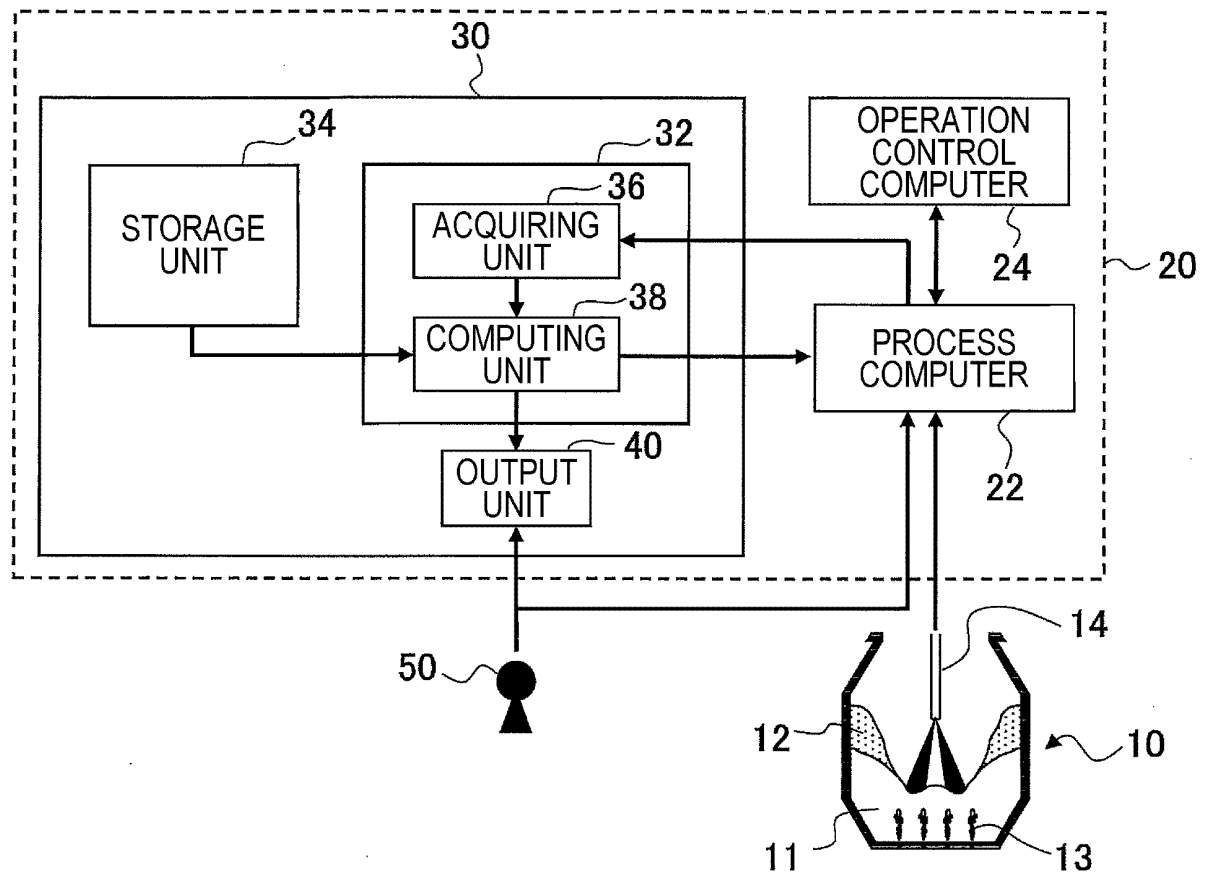
(57) An object is to provide a cold-iron-source melting ratio estimating device that can calculate the melting ratio of a cold iron source using versatile parameters.

A cold-iron-source melting ratio estimating device 30 is configured to estimate a melting ratio of a cold iron source in refining of molten iron using the cold iron source as a raw material. The cold-iron-source melting ratio estimating device 30 includes an acquiring unit 36 configured to acquire in-furnace information including information about the molten iron and the cold iron source; a computing unit 38 configured to calculate, using the in-furnace information, an interfacial carbon concentration

between the cold iron source and the molten iron, a melting rate of the cold iron source, and a melting ratio of the cold iron source; and an output unit 40 configured to output the melting ratio. When the interfacial carbon concentration satisfies a predetermined condition, the computing unit calculates, using an interfacial carbon concentration calculated in the previous step, a first melting rate from a heat transfer balance equation and a second melting rate from a carbon mass balance equation, respectively, and calculates the melting rate of the cold iron source by proportionally distributing the first melting rate and the second melting rate.

EP 4 538 396 A1

FIG. 1



Description

Technical Field

5 **[0001]** The present invention relates to a cold-iron-source melting ratio estimating device and a cold-iron-source melting ratio estimating method for estimating the melting ratio of a cold iron source in refining of molten iron using the cold iron source as a raw material, and also relates to a molten iron refining method using the device and the method described above.

10 Background Art

[0002] To achieve carbon neutrality in 2050, the steel industry, along with other industries, is required to reduce generation of CO₂ gas. The main cause of CO₂ emissions in the steel industry is the use of coal during iron ore reduction in a blast furnace process. Generally, a blast furnace process generates about 2 tons of CO₂ per ton of crude steel in manufacture of steel products. On the other hand, coal is not required when blast furnace pig iron is not used and a cold iron source, such as scrap or reduced iron, is melted by electric power, heat transfer from molten iron, or carburization. Therefore, the amount of CO₂ generated when a cold iron source is used is about 500 kg per ton of crude steel (excluding the amount of CO₂ generated during production of reduced iron). That is, the amount of CO₂ emissions per ton of crude steel can be reduced to about 1/4 of that in the blast furnace process. Therefore, an effective way to reduce the amount of CO₂ emissions in the steel industry is to reduce the use of blast furnace pig iron by reducing the pig iron ratio in a converter, or to increase the use of a cold iron source by introducing an electric arc furnace.

[0003] However, increasing the use of a cold iron source increases the time required to completely melt the cold iron source. When the time required to completely melt the cold iron source increases and the cold iron source cannot be completely melted during processing time, many disadvantages will occur in terms of operation and metallurgy. For example, in dephosphorization blowing of pig iron in a converter, a sub-lance collides with an unmolten cold iron source and this damages the sub-lance. Additionally, an unmolten cold iron source deposited on a bottom blowing tuyere interferes with stirring of pig iron and this results in poor dephosphorization.

[0004] In an electric arc furnace, a cold iron source is additionally charged continuously or intermittently. When the rate of additional charging is too fast with respect to the melting rate, an unmolten cold iron source in the furnace increases, and fusion of cold iron sources may form a huge iron mass. Iron masses have a small ratio of surface area to volume and have a slow melting rate. Formation of iron masses leads to lower productivity and higher power requirements. To efficiently melt the cold iron source, it is important to know whether there is any cold iron source left unmolten in the furnace.

[0005] A main method for knowing whether there is any cold iron source left unmolten is to determine the timing of complete melting of a cold iron source through sensing. Many methods for determining the timing of complete melting of a cold iron source involve using an electric arc furnace. The method monitors the temperature, pressure, vibration, light, and the like inside the furnace to determine the timing of complete melting of the cold iron source from their changes.

[0006] For example, Patent Literatures 1 discloses a method in which a refractory temperature is measured at multiple points in the thickness direction by a temperature measuring probe embedded in the side wall of a converter (furnace) body, and a refractory surface temperature (molten iron temperature) is continuously estimated from the resulting temperature gradient and the residual thickness of the refractory. This method focuses on the fact that after the cold iron source in the furnace is completely melted, the rate of temperature rise of the molten iron increases. Patent Literatures 1 states that the timing of complete melting of the cold iron source can be determined from changes in the temperature of the molten iron.

[0007] Although there are few examples of application to actual operations, a one-dimensional heat transfer model (hereinafter referred to as "cold iron source melting model") that predicts the melting behavior of a cold iron source has been reported. For example, Non Patent Literatures 1 and 2 refer to the cold iron source melting model. In the cold iron source melting models disclosed in Non Patent Literatures 1 and 2, the melting behavior of a cold iron source can be predicted with high accuracy by assuming the coefficient of heat transfer between molten iron and cold iron source and the mass transfer coefficient of molten iron. To apply the cold iron source melting model to actual operations, information obtained by sensing or the like, such as the temperature of molten iron and the carbon concentration in molten iron, is to be continuously or intermittently entered. With the cold iron source melting model, it is possible to predict not only the timing of complete melting of the cold iron source, but also the moment-by-moment melting ratio of the cold iron source. This is advantageous in that the occurrence of unmolten cold iron source can be predicted during processing.

55

Citation List

Patent Literature

- 5 **[0008]** PTL 1: Japanese Unexamined Patent Application Publication No. 8-3614

Non Patent Literature

[0009]

10

NPL 1: Masahiro Kawakami and two others, "Heat and Mass Transfer Analysis of Scrap Melting in Steel Bath", Tetsu-to-Hagané, vol. 85(1999), pp. 658-665

NPL 2: Kohichi Isobe and four others, "Analysis of the Scrap Melting Rate in High Carbon Molten Iron", Tetsu-to-Hagané, vol. 76(1990), pp. 2033-2040

15

Summary of Invention

Technical Problem

20

[0010] Patent Literature 1 does not refer to a threshold for the rate of temperature rise of molten iron, which serves as a criterion for determining the timing of complete melting of the cold iron source, and the determination depends on the subjectivity of the observer. Additionally, in actual operations, where changes in the temperature of molten iron are varied by a factor, such as changing the flow rate of top and bottom blowing, the determination may be subject to error or may be delayed.

25

[0011] Examples of the driving force for melting the cold iron source include heat transfer and carburization (mass transfer from molten iron to the surface layer of the cold iron source). When the carbon concentration in the molten iron does not exceed the carbon concentration in the cold iron source, or in the presence of a solidified element, carburization will not occur and the driving force for melting the cold iron source is heat transfer alone. Therefore, in calculating the melting rate of the cold iron source, only a heat balance near the interface between the molten iron and the cold iron source is to be taken into account. On the other hand, when the carbon concentration in the molten iron exceeds the carbon concentration in the cold iron source, carburization will occur after a solidified element is remelted. Therefore, in calculating the melting rate of the cold iron source, a carbon mass balance, rather than a heat balance, near the interface is to be taken into account. It is common, as described above, to change the formula for calculating the melting rate, in accordance with the driving force for melting the cold iron source. However, the mechanism of melting cannot be clearly identified in practice.

35

[0012] For example, even in the case where the carbon concentration in the molten iron exceeds the carbon concentration in the cold iron source and carburization occurs, when the temperature of the molten iron is as high as or above the liquidus-line temperature of the cold iron source, it is unlikely that heat transfer does not at all contribute to melting of the cold iron source, and both carburization and heat transfer are to be taken into account as mechanisms for melting. However, in the cold iron source melting models of the related art, the driving force is limited to carburization or heat transfer.

40

[0013] The cold iron source melting models disclosed in Non Patent Literatures 1 and 2 ensure accuracy by using a heat transfer coefficient and a mass transfer coefficient as fitting parameters. However, the values of the fitting parameters are described only for the conditions of the specific molten iron and cold iron source referred to in the literatures, and are less versatile. The present invention has been made in view of the problems described above. An object of the present invention is to provide a cold-iron-source melting ratio estimating device and a cold-iron-source melting ratio estimating method that can calculate the melting ratio of a cold iron source using versatile parameters, and to also provide a molten iron refining method using the device and the method described above. Solution to Problem

45

[0014] The means for solving the problems described above are as follows.

50

[1] A cold-iron-source melting ratio estimating device is configured to estimate a melting ratio of a cold iron source in refining of molten iron using the cold iron source as a raw material. The cold-iron-source melting ratio estimating device includes an acquiring unit configured to acquire in-furnace information including information about the molten iron and the cold iron source; a computing unit configured to calculate, using the in-furnace information, an interfacial carbon concentration between the cold iron source and the molten iron, a melting rate of the cold iron source, and a melting ratio of the cold iron source; and an output unit configured to output the melting ratio. When the interfacial carbon concentration satisfies at least one of inequalities (1) and (2) described below, the computing unit calculates, using an interfacial carbon concentration calculated in the previous step, a first melting rate from a heat transfer

55

balance equation and a second melting rate from a carbon mass balance equation, respectively, and calculates the melting rate of the cold iron source by proportionally distributing the first melting rate and the second melting rate. When the interfacial carbon concentration satisfies neither of inequalities (1) and (2) described below, the computing unit calculates the first melting rate or the second melting rate using the interfacial carbon concentration, and determines the calculated first or second melting rate to be the melting rate of the cold iron source.

$$C_i > C \quad \cdots \quad (1)$$

$$C_i > C_{i, t-1} \quad \cdots \quad (2)$$

In inequalities (1) and (2) described above, C is a carbon concentration (% by mass) in molten iron, C_i is an interfacial carbon concentration (% by mass), and $C_{i, t-1}$ is an interfacial carbon concentration (% by mass) calculated in the previous step.

[2] In the cold-iron-source melting ratio estimating device according to [1], when a carbon concentration in the cold iron source is lower than a carbon concentration in the molten iron, the computing unit determines a proportional distribution ratio for proportionally distributing the first melting rate and the second melting rate on the basis of a temperature of the molten iron, the carbon concentration in the molten iron, and the carbon concentration in the cold iron source.

[3] In the cold-iron-source melting ratio estimating device according to [1] or [2], the computing unit estimates a moment-by-moment melting ratio of the cold iron source by repeatedly calculating the interfacial carbon concentration, the melting rate of the cold iron source, and the melting ratio of the cold iron source.

[4] A molten iron refining method includes estimating a melting ratio of the cold iron source at an end of the refining by using the cold-iron-source melting ratio estimating device according to any one of [1] to [3]; and performing, when a ratio of an unmolten cold iron source calculated from the melting ratio at the end of the refining exceeds 5% by mass, at least one of adding a heating material and extending a molten iron treatment.

[5] A cold-iron-source melting ratio estimating method is for estimating a melting ratio of a cold iron source in refining of molten iron using the cold iron source as a raw material. The cold-iron-source melting ratio estimating method includes an acquiring step of acquiring in-furnace information including information about the molten iron and the cold iron source; a computing step of calculating, using the in-furnace information, an interfacial carbon concentration between the cold iron source and the molten iron, a melting rate of the cold iron source, and a melting ratio of the cold iron source; and an outputting step of outputting the melting ratio. When the interfacial carbon concentration satisfies at least one of inequalities (1) and (2) described below, the computing step calculates, using an interfacial carbon concentration calculated in the previous step, a first melting rate from a heat transfer balance equation and a second melting rate from a carbon mass balance equation, respectively, and calculates the melting rate of the cold iron source by proportionally distributing the first melting rate and the second melting rate. When the interfacial carbon concentration satisfies neither of inequalities (1) and (2) described below, the computing step calculates the first melting rate or the second melting rate using the interfacial carbon concentration, and determines the calculated first or second melting rate to be the melting rate of the cold iron source.

$$C_i > C \quad \cdots \quad (1)$$

$$C_i > C_{i, t-1} \quad \cdots \quad (2)$$

In inequalities (1) and (2) described above, C is a carbon concentration (% by mass) in molten iron, C_i is an interfacial carbon concentration (% by mass), and $C_{i, t-1}$ is an interfacial carbon concentration (% by mass) calculated in the previous step.

[6] In the cold-iron-source melting ratio estimating method according to [5], when a carbon concentration in the cold iron source is lower than a carbon concentration in the molten iron, the computing step determines a proportional distribution ratio for proportionally distributing the first melting rate and the second melting rate on the basis of a temperature of the molten iron, the carbon concentration in the molten iron, and the carbon concentration in the cold iron source.

[7] In the cold-iron-source melting ratio estimating method according to [5] or [6], the computing step estimates a moment-by-moment melting ratio of the cold iron source by repeatedly calculating the interfacial carbon concentration, the melting rate of the cold iron source, and the melting ratio of the cold iron source.

[8] A molten iron refining method includes estimating a melting ratio of the cold iron source at an end of the refining by using the cold-iron-source melting ratio estimating method according to any one of [5] to [7]; and performing, when a

ratio of an unmolten cold iron source calculated from the melting ratio at the end of the refining exceeds 5% by mass, at least one of adding a heating material and extending a molten iron treatment. Advantageous Effects of Invention

[0015] In the present invention, the melting ratio of a cold iron source can be calculated by using a proportional distribution ratio that can be determined more easily than fitting parameters. Accordingly, the cold-iron-source melting ratio estimating method according to the present invention is a more versatile method for calculating the melting ratio of the cold iron source than the methods of the related art.

Brief Description of Drawings

[0016]

[Fig. 1] Fig. 1 is a schematic diagram of a converter-type refining furnace including a cold-iron-source melting ratio estimating device according to the present invention.

[Fig. 2] Fig. 2 is a graph illustrating a proportional distribution ratio at a pig iron temperature of 1450°C to 1480°C in Table 1.

[Fig. 3] Fig. 3 is a flowchart illustrating the flow of a cold-iron-source melting ratio estimating method.

[Fig. 4] Fig. 4 is a graph illustrating results of estimation and actual measurement of the melting ratio of a square pure iron sample in Example 1.

[Fig. 5] Fig. 5 is a graph illustrating results of estimation and actual measurement of the melting ratio of a square pure iron sample in Example 2.

[Fig. 6] Fig. 6 is a graph illustrating results of estimation and actual measurement of the melting ratio of a square pure iron sample in Example 3.

Description of Embodiments

[0017] An exemplary embodiment of the present invention will now be described with reference to the accompanying drawings. Fig. 1 is a schematic diagram of a converter-type refining furnace including a cold-iron-source melting ratio estimating device according to the present invention. In Fig. 1, reference numeral 10 denotes a converter-type refining furnace, reference numeral 20 denotes a converter-type refining furnace control apparatus, and reference numeral 50 denotes an operator. The converter-type refining furnace control apparatus 20 includes a process computer 22, an operation control computer 24, and a cold-iron-source melting ratio estimating device 30.

[0018] After iron scrap is charged as a cold iron source into the converter-type refining furnace 10 using a scrap chute, pig iron 11 is charged into the furnace using a charging ladle. Oxygen gas (industrial grade pure oxygen) is supplied from a top blowing lance 14 toward the pig iron 11 charged in the furnace, and stirring gas 13 is blown from a tuyere (not illustrated) installed at the bottom of the furnace into the pig iron 11 in the furnace. While being stirred by the stirring gas 13, the pig iron 11 charged in the furnace is oxidized and refined by the oxygen gas supplied from the top blowing lance 14. Generally, as a refining method, preliminary dephosphorization of the pig iron 11 and decarbonization of the pig iron 11 (hereinafter also referred to as "decarbonization refining") are performed in the converter-type refining furnace 1.

[0019] In the preliminary dephosphorization of the pig iron 11, iron scrap is first charged as a cold iron source into the converter-type refining furnace 10 using the scrap chute (not illustrated). Then, the pig iron 11 is charged into the furnace using the charging ladle (not illustrated). Charging the pig iron 11 is followed by supplying oxygen gas from the top blowing lance 14, supplying nitrogen gas or the like as the stirring gas 13 from the tuyere at the bottom of the furnace, and adding auxiliary materials, such as a heating material and flux, so as to perform preliminary dephosphorization of the pig iron 11.

[0020] The preliminary dephosphorization of the pig iron 11 in the converter-type refining furnace 1 involves oxidizing phosphorus in the pig iron with the oxygen gas to form phosphorus oxide (P_2O_5), and fixing the phosphorus oxide in a stable form $3CaO \cdot P_2O_5 (= Ca_3(PO_4)_2)$ to slag 12 formed by CaO-based flux. The preliminary dephosphorization of the pig iron 11 ends when a phosphorus concentration in the pig iron 11 in the furnace reaches a predetermined value (e.g., 0.050% by mass or less). After the preliminary dephosphorization, dephosphorized pig iron is produced in the furnace.

[0021] Charging the pig iron 11 after the preliminary dephosphorization is followed by supplying oxygen gas from the top blowing lance 14, supplying the stirring gas 13 from the tuyere at the bottom of the furnace, and adding auxiliary materials, such as a cooling material, a heating material, and flux, at appropriate times to decarbonize the pig iron 11.

[0022] Decarbonization of the pig iron 11 proceeds by a decarbonizing reaction ($C + O \rightarrow CO$) between oxygen gas and carbon in molten iron, and is carried out until a carbon concentration in the molten iron in the furnace reaches a predetermined value (e.g., 0.05% by mass or less). After the decarbonization, decarbonized molten steel is produced in the furnace. Here, "molten iron" is either pig iron or molten steel. In decarbonization of the pig iron 11, the pig iron in the furnace turns into molten steel, as the decarbonization proceeds. Since it is difficult to distinguish between pig iron and molten steel in molten metal in the furnace during decarbonization, pig iron and molten steel are collectively referred to as

"molten iron".

[0023] The process computer 22 is a device configured to calculate the amount of oxygen to be supplied and the necessity and amount of input of cooling material or heating material so that a pig iron temperature and a pig iron component concentration at the end of preliminary dephosphorization and a molten iron temperature and a molten iron component concentration at the end of decarbonization are brought to target values.

[0024] The operation control computer 24 is a device configured to control operating conditions (e.g., the amount of oxygen gas to be supplied, lance height, the amount of stirring gas to be supplied, and the amount of input of auxiliary materials) on the basis of the amount of oxygen and the amount of input of cooling material or heating material calculated by the process computer 22 so that a pig iron temperature and a pig iron component concentration at the end of preliminary dephosphorization and a molten steel temperature and a molten steel component concentration at the end of decarbonization are brought to target values. Signals from the operation control computer 24 are fed back to the process computer 22 to further accurately control the refining. Hereinafter, a description will be given using an example in which the cold-iron-source melting ratio estimating device 30 according to the present embodiment is applied to preliminary dephosphorization of the pig iron 11 using the converter-type refining furnace 10 where iron scrap (cold iron source) having a carbon concentration lower than that in the pig iron 11 is used as a raw material. The cold-iron-source melting ratio estimating device 30 is applicable not only to the converter-type refining furnace 10, but also to an electric arc refining furnace and is also applicable to decarbonization of the pig iron 11.

[0025] The cold-iron-source melting ratio estimating device 30 is a computing device constituting part of the converter-type refining furnace control apparatus 20. The cold-iron-source melting ratio estimating device 30 includes a controller 32, a storage unit 34, and an output unit 40. The controller 32 is, for example, a CPU. The controller 32 executes programs read from the storage unit 34 to serve as an acquiring unit 36 and a computing unit 38.

[0026] The output unit 40 is, for example, an LCD or a CRT display. The storage unit 34 includes, for example, an information recording medium, such as an updatable and recordable flash memory, a hard disk that is internal or connected by a data communication terminal, or a memory card, and a reading and writing device configured to read and write data from and to the information recording medium. The storage unit 34 records not only programs for executing the functions of the acquiring unit 36 and the computing unit 38, but also computing equations, data, and the like used in the programs.

[0027] Processing performed by the acquiring unit 36 and the computing unit 38 will now be described. Through the process computer 22, the acquiring unit 36 acquires in-furnace information entered by the operator 50, or from an in-furnace sensor installed in the converter-type refining furnace 10. The in-furnace information includes information about the pig iron 11 and the iron scrap. Specifically, the in-furnace information includes the amount of the pig iron 11 charged into the furnace, an initial carbon concentration in the pig iron 11, the amount of the iron scrap charged, an initial carbon concentration in the iron scrap, the density of the iron scrap, and a latent heat for melting of the iron scrap. In addition to the information described above, the acquiring unit 36 acquires, as the in-furnace information, the moment-by-moment temperature of the pig iron 11, the flow rate of bottom blowing of the stirring gas 13, and furnace pressure. The acquiring unit 36 outputs the acquired in-furnace information to the computing unit 38.

[0028] The computing unit 38 calculates, using the in-furnace information, an interfacial carbon concentration between the iron scrap and the pig iron 11 charged into the converter-type refining furnace 10, the melting rate of the iron scrap, and the melting ratio of the iron scrap. The computing unit 38 first calculates the interfacial carbon concentration between the pig iron 11 and the iron scrap. When the interfacial carbon concentration calculated satisfies at least one of inequalities (1) and (2) described below, the computing unit 38 calculates, using an interfacial carbon concentration calculated in the previous step, a first melting rate from a heat transfer balance equation and a second melting rate from a carbon mass balance equation, respectively. The computing unit 38 then calculates the melting rate of the iron scrap by proportionally distributing the first melting rate and the second melting rate. Note that when at least one of inequalities (1) and (2) described below was satisfied also in calculation in the previous step, an interfacial carbon concentration calculated in the second previous step is used.

$$C_i > C \quad \cdots \quad (1)$$

$$C_i > C_{i, t-1} \quad \cdots \quad (2)$$

[0029] In inequalities (1) and (2) described above, C is a carbon concentration (% by mass) in the pig iron 11, C_i is an interfacial carbon concentration (% by mass), and $C_{i, t-1}$ is an interfacial carbon concentration (% by mass) calculated in the previous step. In the following description, the subscript "t-1" indicates that the value was calculated in the previous step.

[0030] As described above, the computing unit 38 calculates the melting rate of the iron scrap by proportionally distributing the first melting rate calculated from the heat balance equation and the second melting rate derived from carbon mass balance in a proportional distribution ratio. As an example, Table 1 shows values of the proportional

distribution ratio at a carbon concentration of 0.05% by mass in a cold iron source.

[Table 1]

Proportional Distribution Ratio		Molten Iron Temperature [°C]											
		1240- 1270	1270- 1300	1300- 1330	1330- 1360	1360- 1390	1390- 1420	1420- 1450	1450- 1480	1480- 1510	1510- 1540	1540- 1570	1570
Carbon Concentration in Molten Iron [% by mass]	4.5-4.0	0.98	0.97	0.95	0.93	0.88	0.82	0.75	0.68	0.50	0.37	0.20	0.00
	4.0-3.5	0.99	0.98	0.97	0.95	0.94	0.90	0.82	0.69	0.50	0.35	0.10	0.00
	3.5-3.0	1.00	0.99	0.98	0.96	0.94	0.92	0.87	0.70	0.50	0.33	0.00	0.00
	3.0-2.5	-	1.00	0.99	0.98	0.96	0.94	0.92	0.73	0.51	0.30	0.00	0.00
	2.5-2.0	-	-	-	1.00	0.99	0.98	0.95	0.77	0.53	0.25	0.00	0.00
	2.0-1.5	-	-	-	-	1.00	0.99	0.98	0.80	0.55	0.10	0.00	0.00
	1.5-1.0	-	-	-	-	-	-	1.00	0.90	0.58	0.00	0.00	0.00
	1.0-0.5	-	-	-	-	-	-	-	1.00	0.60	0.00	0.00	0.00
	0.5-0.0	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00

[0031] The proportional distribution ratios for proportionally distributing the first melting rate and the second melting rate, shown in Table 1, are prepared in advance for each carbon concentration in the cold iron source and stored in the storage unit 34.

[0032] Fig. 2 is a graph illustrating a proportional distribution ratio at a pig iron temperature of 1450°C to 1480°C in Table 1. In Fig. 2, the horizontal axis represents a carbon concentration (% by mass) in molten iron and the vertical axis represents a proportional distribution ratio (-). As illustrated in Fig. 2, a proportional distribution ratio at each carbon concentration in molten iron is plotted on a predetermined curve. For example, three points representing proportional distribution ratios at different carbon concentrations in molten iron are determined to form a curve (indicated by a broken line in Fig. 2) using the three points, so that proportional distribution ratios at other carbon concentrations in molten iron can be determined. The proportional distribution ratios can thus be determined more easily than fitting parameters of the related art. Therefore, the cold-iron-source melting ratio estimating method according to the present embodiment using the proportional distribution ratios can be considered a more versatile method for calculating the melting ratio of a cold iron source than the methods of the related art.

[0033] The computing unit 38 reads, from the storage unit 34, a table of proportional distribution ratios corresponding to carbon concentrations in iron scrap, and identifies, as a proportional distribution ratio, a value in the table corresponding to the temperature of the pig iron 11 and the carbon concentration in the molten iron. That is, the computing unit 38 identifies a proportional distribution ratio on the basis of the molten iron temperature, the carbon concentration in the molten iron, and the carbon concentration in the cold iron source.

[0034] The computing unit 38 calculates the melting rate of the iron scrap by proportionally distributing the first melting rate and the second melting rate in the identified proportional distribution ratio. When the interfacial carbon concentration calculated satisfies neither of inequalities (1) and (2) described above, the computing unit 38 calculates the first melting rate or the second melting rate using the interfacial carbon concentration calculated. Since the first melting rate and the second melting rate are the same melting rate in this case, the first melting rate or the second melting rate is taken as the melting rate of the iron scrap.

[0035] The computing unit 38 calculates the melting ratio of the iron scrap using the calculated melting rate of the iron scrap. The computing unit 38 thus calculates the melting ratio of the iron scrap using in-furnace information.

[0036] The computing unit 38 outputs the calculated melting ratio of the iron scrap to the output unit 40. The output unit 40 displays the result of calculation of the melting ratio of the iron scrap such that it can be seen by the operator 50 who is operating the converter-type refining furnace 10. This allows the operator 50 to check on the display of the output unit 40 the degree to which the iron scrap is melted during the charging process, and perform operation in accordance with the melting ratio of the iron scrap. For example, the melting ratio of the iron scrap at the end of preliminary dephosphorization of the pig iron 11 is estimated, and when the ratio of unmolten iron scrap calculated from the melting ratio exceeds 5% by mass, at least one of adding a heating material and extending preliminary dephosphorization of the molten iron is preferably performed. This can reduce the amount of unmolten iron scrap at the end of the preliminary dephosphorization.

[0037] A method for calculating the melting ratio of the iron scrap in the computing unit 38 will now be described. Note that equations relating to iron scrap, such as those relating to physical property values and melting rates of iron scrap, are calculated for each brand of iron scrap. The mass of the pig iron 11 and the carbon concentration in the pig iron 11 to be used in calculation are calculated using equations (3) and (4) described below.

[Math 1]

$$W = W_0 + W_{S0} \times \frac{S_{m,t-1}}{100} \quad \dots (3)$$

$$C = \begin{cases} C_0 & (S_{m,t-1} < 0) \\ \frac{C_0 \times W_0 + C_{S0} \times W_{S0} \times S_{m,t-1}/100}{W_0 + W_{S0} \times S_{m,t-1}/100} & (S_{m,t-1} \geq 0) \end{cases} \quad \dots (4)$$

[0038] Here, W is the mass (tons) of the pig iron 11 in the furnace, W_0 is the amount (tons) of the pig iron 11 charged, W_{S0} is the amount (tons) of the iron scrap charged, S_m is the melting ratio (% by mass) of the iron scrap, C is the carbon concentration (% by mass) in the pig iron 11, C_0 is the initial carbon concentration (% by mass) in the pig iron 11, and C_{S0} is the initial carbon concentration (% by mass) in the iron scrap.

[0039] In equation (4), the carbon concentration C in the pig iron 11 changes only with the melting ratio S_m of the iron scrap, and, for example, the effect of decarbonization caused by a reaction with blowing oxygen or atmospheric oxygen is not taken into account. That is, in the presence of a solidified shell (melting ratio $S_m < 0$), the carbon concentration C in the pig iron 11 remains unchanged at the initial carbon concentration. When the converter-type refining furnace 10 includes a means to measure the carbon concentration C in the pig iron 11, measured values of the carbon concentration C may be used without calculating equation (4).

[0040] When the cold-iron-source melting ratio estimating device 30 according to the present embodiment is applied to decarbonization, the calculated carbon concentration C in the molten steel is expected to deviate from the actual carbon concentration in the molten steel in the final stage of treatment where decarbonization progresses. However, since the temperature of the molten steel is high in the final stage of decarbonization, the effect of the carbon concentration C in the molten steel on the melting rate of the iron scrap is small and the melting ratio S_m of the cold iron source does not deviate significantly.

[0041] Physical property values and the like of the pig iron 11 are calculated using equations (5) to (12) described below.

[Math 2]

$$\rho = 7.09 - 0.07 \times C \quad \dots (5)$$

$$\varepsilon_B = 3.71 \times 10^2 \times \frac{Q_B/60 \times (T+273.15)}{W \times 10^3} \times \ln \left(1 + \frac{P \times 10^3 \times g \times L}{P} \right) \times 10^3 \quad \dots (6)$$

$$h = 5000 \times (\varepsilon_B \times \rho)^{0.2} \quad \dots (7)$$

$$D = 1.3877 \times 10^{-7} \times \exp \left(- \frac{0.556 \times 10^4}{T+273.15} \right) \quad \dots (8)$$

[0042] Here, ρ is the density (tons/m³) of the pig iron 11, ε_B is stirring power (W/ton) of bottom blowing, Q_B is the flow rate (Nm³/min) of bottom blowing, T is the temperature (°C) of the pig iron 11, g is gravitational acceleration (m/s²), L is a bath depth (m), P is furnace pressure (Pa), h is an interfacial heat transfer coefficient (W/(m²·K)) between pig iron and iron scrap, and D is a diffusion coefficient (m²/s) of the pig iron 11.

[Math 3]

$$\alpha = 6.2 \times 10^{-6} + 1.79 \times 10^{-9} \times (T - 1537.85) \quad \dots (9)$$

$$\lambda = 4.184 \times \alpha \times C_p \times \rho \times 10^6 \quad \dots (10)$$

$$\log \mu = \frac{2920}{T+273.15} - 0.897 \quad \dots (11)$$

$$k = Sc^{1/3} \times Pr^{-1/3} \times \frac{h \times D}{\lambda} = \left(\frac{\mu / (\rho \times 10^{-6})}{D} \right)^{1/3} \times \left(\frac{\mu / (\rho \times 10^{-6})}{\alpha} \right)^{-1/3} \times \frac{h \times D}{\lambda} \quad \dots (12)$$

[0043] Here, α is the thermal diffusivity (m²/s) of the pig iron 11, C_p is the specific heat (kcal/(kg·K)) of the pig iron 11, λ is

the thermal conductivity (W/(m·K)) of the pig iron 11, μ is the viscosity (mPa·s) of the pig iron 11, k is the mass transfer coefficient (m/s) of the pig iron 11, Sc is Schmidt number (-), and Pr is Prandtl number (-). Equation (5) is an empirical equation derived from the melting behavior of scrap in the 310-ton top-blowing converter to the 240-ton bottom-blowing converter described in Publication 1 below. Equation (10) is an equation derived from the Chilton-Colburn analogy. The sign (-) indicates that the value is dimensionless.

[0044] Publication 1: H. Gaye, M. Wanin, P. Gugliermi, and P. Schittly: 68th Steelmaking Conf. Proc., ISS, Detroit, MI, USA, (1985), 91.

[0045] An interfacial carbon concentration between pig iron and iron scrap (hereinafter referred to as "interfacial carbon concentration") and an interfacial temperature between molten iron and a cold iron source (hereinafter referred to as "interfacial temperature") are calculated using equations (13) to (15) described below. Equation (13) described below is a heat transfer balance equation near the interface, equation (14) described below is a carbon mass balance equation near the interface, and equation (15) described below is a relational equation between an interfacial temperature and a carbon concentration. The interfacial carbon concentration and the interfacial temperature are calculated using these three equations.

[Math 4]

$$h \times (T - T_i) = \rho_s \times H_s \times v + \lambda_{i,t-1} \times \left(\frac{\partial T_s}{\partial x} \right)_{i,t-1} \cdot \cdot \cdot \quad (13)$$

$$k \times (C - C_i) = v \times (C_i - C_{s0}) \cdot \cdot \cdot \quad (14)$$

$$T_i = T_{L,0,t-1} + a_{t-1} \times C_i \cdot \cdot \cdot \quad (15)$$

[0046] Here, T_i is an interfacial temperature (°C), T_s is the temperature (°C) of a cold iron source, ρ_s is the density (tons/m³) of iron scrap, H_s is a latent heat (MJ/ton) for melting of iron scrap, v is the melting rate (mm/s) of iron scrap ($v > 0$: melting, $v < 0$: growing (forming of a solidified shell)), and λ_i is a thermal conductivity (W/(m·K)) at the interface between pig iron and iron scrap (thermal conductivity on the pig iron side of the interface). $T_{L,0}$ is the liquidus-line temperature (°C) of pure iron (carbon concentration of 0% by mass), and a is a coefficient.

[0047] The coefficient and the liquidus-line temperature of pure iron in equation (15) described above are calculated by equations (16) and (17) described below. The coefficient and the liquidus-line temperature of pure iron calculated by equations (16) and (17) described below are used in calculating C_i in the next step.

[Math 5]

$$a = -6.0902 \times C_i - 81.11 \cdot \cdot \cdot \quad (16)$$

$$T_{L,0} = 3.0451 \times C_i^2 + 1539.5 \cdot \cdot \cdot \quad (17)$$

[0048] A heat transfer coefficient at the interface between pig iron and iron scrap (hereinafter referred to as "interfacial heat transfer coefficient") is calculated by equation (18) described below. The interfacial heat transfer coefficient calculated by equation (18) is used in calculating an interfacial carbon concentration in the next step.

[Math 6]

$$\lambda_i = 76.017 \times \exp(-0.001 \times T_i) \quad (\text{minimum value: } 27) \cdot \cdot \cdot$$

(18)

[0049] When the interfacial carbon concentration calculated here satisfies at least one of inequalities (1) and (2) described below, the first melting rate is calculated from equation (13) described above and the second melting rate is calculated from equation (14) described above, using an interfacial carbon concentration calculated in the previous step, instead of the interfacial carbon concentration calculated, and the melting rate of the iron scrap is calculated by proportionally distributing the first melting rate and the second melting rate.

$$C_i > C \cdot \cdot \cdot \quad (1)$$

$$C_i > C_{i, t-1} \dots (2)$$

[0050] When the interfacial carbon concentration calculated in the previous step is used instead of the interfacial carbon concentration calculated, the first melting rate calculated from equation (13) and the first melting rate calculated from equation (14) will be different values. The computing unit 38 calculates the melting rate of the iron scrap by proportionally distributing the first melting rate and the second melting rate in a specific proportional distribution ratio.

[0051] As described above, in calculating the melting rate of the iron scrap, equation (13) and equation (14) are preferably used depending on the driving force for melting the iron scrap. In practice, however, it is difficult to clearly identify the mechanism for melting the iron scrap. Therefore, when only either one of equation (13) and equation (14) is used to calculate the melting rate of the iron scrap, the melting rate of the iron scrap agreeing with an actual phenomenon cannot be obtained.

[0052] To improve the accuracy of estimating the melting rate of the iron scrap, therefore, the computing unit 38 calculates the melting rate of the iron scrap by proportionally distributing the first melting rate calculated from equation (13) and the second melting rate calculated from equation (14) in a specific proportional distribution ratio. Specifically, the melting rate of the iron scrap is calculated by equation (19) described below.

$$v_s = (\text{first melting rate}) \times (1-Z) + (\text{second melting rate}) \times Z \quad (19)$$

[0053] Here, v_s is the melting rate of iron scrap (m/min), and Z is a proportional distribution ratio (-).

[0054] When the interfacial carbon concentration calculated satisfies neither of inequalities (1) and (2) described above, the melting rate of the iron scrap is calculated using the interfacial carbon concentration. In the case of using the interfacial carbon concentration calculated and the interfacial temperature, the first melting rate calculated from equation (13) and the second melting rate calculated from equation (14) are equal. Therefore, in this case, the first melting rate or the second melting rate calculated using the interfacial carbon concentration is determined to be the melting rate of the iron scrap. The computing unit 38 thus calculates the melting rate of the iron scrap.

[0055] When the melting rate of the iron scrap can be calculated, the melting ratio of the iron scrap can be calculated using the melting rate of the iron scrap and equation (20) described below.

[Math 7]

$$S_m = S_{m,t-1} + \frac{v_s \times \Delta t}{t_{s0}} \times 100 \dots (20)$$

[0056] Here, t_{s0} is the initial thickness (mm) of iron scrap, and Δt is a calculation time interval [s].

[0057] Finally, a temperature distribution in the iron scrap is determined using equation (21) and equation (22) described below.

[Math 8]

$$\frac{\partial T_s}{\partial t} = \alpha_s \times \frac{\partial^2 T_s}{\partial x^2} \dots (21)$$

$$\frac{T_s - T_{s,t-1}}{\Delta t} = \alpha_s \times \frac{T_{s,i+1,t-1} - 2T_{s,t-1} + T_{s,i-1,t-1}}{\Delta x^2} \dots (22)$$

[0058] Here, α_s is the thermal diffusivity (m^2/s) of iron scrap, x is a position in the thickness direction of iron scrap, and one unit of x in the present embodiment is $t_{s0}/100$. A subscript $i+1$ denotes the iron scrap temperature of a calculation element adjacent to a molten iron element and a subscript $i-1$ denotes the iron scrap temperature of a calculation element adjacent to the side to the center of the iron scrap.

[0059] A temperature distribution in the iron scrap is one-dimensionally determined using equation (21) described above. Calculating equation (21) requires discretization, as in equation (22) described above. Therefore, the temperature distribution in the iron scrap obtained from equation (22) is a discrete temperature distribution for each calculation thickness interval Δx .

[0060] Since the thickness interval Δx is set to $1/100$ of t_{s0} , there are 100 calculation elements representing iron scrap at the start of calculation (or at the start of melting). One calculation element representing an interface is adjacent to the iron scrap element group, and a calculation element group representing molten iron is adjacent to the opposite side of the

interface element. The initial number of molten iron elements is any value, but is preferably determined on the basis of the allowable calculation cost. Although the calculation cost increases as the number of elements increases, the melting behavior can be accurately calculated when the solidified shell expands significantly at the early stage of melting of iron scrap.

[0061] The thickness of all the calculation elements is Δx . The thickness of the calculation elements, the number of interface elements, and the total number of the calculation elements are constant during calculation. However, the number of iron scrap elements and the number of molten iron elements during calculation change in accordance with the moment-by-moment melting ratio S_m of iron scrap determined from equation (20) described above. For example, when the melting ratio is 2% by mass at a given point in time, the number of iron scrap elements at this point in time is 98, and the number of molten iron elements increases by two. Since the interface element is always present between the iron scrap element group and the molten iron element group, the interface element is shifted by a distance of $2 \times \Delta x$ to the side of the iron scrap elements from the initial position. On the other hand, when the melting ratio is less than 0 (during forming of a solidified shell), the number of iron scrap elements increases and the number of molten iron elements decreases, so that the interface element is shifted toward the side of the molten iron elements.

[0062] A temperature distribution calculation first determines, in accordance with the melting ratio of iron scrap at the time, that each calculation element is the iron scrap element, the interface element, or the molten iron element, and then determines the temperature distribution for each element as follows.

[0063] Iron scrap element: calculated in accordance with equation (22) described above. Note that the center of iron scrap is treated as an adiabatic boundary (having the same temperature as adjacent elements).

[0064] Interface element: an interfacial temperature T_i calculated from equation (15) described above.

[0065] Molten iron element: a molten iron temperature T . Temperature variation in molten iron is not taken into account.

[0066] dT_S/dx used in equation (13) in the next step is calculated by dividing the temperature difference between the interfacial temperature T_i and the iron scrap element adjacent to the interfacial temperature by the thickness Δx of calculation elements. After dT_S/dx used in equation (13) in the next step is calculated, in-furnace information may be acquired again to calculate the melting ratio of iron scrap after the calculation time interval Δt (in seconds) using equations (3) to (21) described above. Thus, repeatedly calculating the melting ratio of iron scrap can determine the moment-by-moment melting ratio of iron scrap during the preliminary dephosphorization of the pig iron 11.

[0067] The thermal diffusivity of the iron scrap in equation (21) and equation (22) described above can be calculated by equation (23), equation (24), and equation (25) described below.

[Math 9]

$$\alpha_s = \frac{\lambda_s}{\rho_s \times C_{ps} \times 10^6} \quad \dots \quad (23)$$

$$\lambda_s = 76.017 \times \exp(-0.001 \times T_s) \text{ (minimum value: 27)} \quad \dots \quad (24)$$

$$C_{ps} = \frac{1}{55.845} \times \{24.5 + 8.45 \times 10^{-3} \times (T_s + 273.15)\} \quad \dots \quad (25)$$

[0068] Here, λ_s is the thermal conductivity (W/(m $\times$ K)) of iron scrap, and C_{ps} is the specific heat (MJ/(t $\times$ K)) of iron scrap.

[0069] Fig. 3 is a flowchart illustrating the flow of a cold-iron-source melting ratio estimating method. A process of a cold-iron-source melting ratio estimating method according to the present embodiment will be described using Fig. 3. The cold-iron-source melting ratio estimating method according to the present embodiment is started, for example, by an instruction from the operator 50 at any time point before and during preliminary dephosphorization of the pig iron 11.

[0070] The acquiring unit 36 of the cold-iron-source melting ratio estimating device 30 performs an acquiring step to acquire, as in-furnace information, information about the pig iron 11 and iron scrap, such as the amount of the pig iron 11 charged into the furnace, an initial carbon concentration in the pig iron 11, the amount of the iron scrap charged, an initial carbon concentration in the iron scrap, the density of the iron scrap, and a latent heat for melting of the iron scrap. At the same time, the acquiring unit 36 acquires, as in-furnace information, the flow rate of bottom blowing of the stirring gas 13, the moment-by-moment temperature of the pig iron 11, and furnace pressure (step S101). The acquiring unit 36 outputs the in-furnace information to the computing unit 38.

[0071] The computing unit 38 performs a computing step to calculate the interfacial carbon concentration C_i using the in-furnace information and equations (3) to (18) described above (step S102). When the interfacial carbon concentration C_i calculated satisfies at least one of inequalities (1) and (2) described above, the computing unit 38 calculates the first melting rate and the second melting rate using the interfacial carbon concentration $C_{i, t-1}$ calculated in the previous step,

instead of the interfacial carbon concentration C_i calculated, and calculates the melting rate of iron scrap by proportionally distributing the first melting rate and the second melting rate. When the interfacial carbon concentration C_i calculated satisfies neither of inequalities (1) and (2) described above, the computing unit 38 calculates the first melting rate or the second melting rate using the interfacial carbon concentration C_i calculated, and determines the calculated first or second melting rate to be the melting rate of the iron scrap (step S103).

[0072] The computing unit 38 performs a computing step to calculate the melting ratio S_m of the iron scrap using the melting rate of the iron scrap and equation (20) described above (step S104). Also, the computing unit 38 performs a computing step to calculate a temperature distribution in the iron scrap using equation (21) described above (step S105).

[0073] The computing unit 38 outputs the melting ratio S_m of the iron scrap to the output unit 40. The output unit 40 performs an outputting step to output the melting ratio S_m (step S106).

[0074] The computing unit 38 determines whether the calculated melting ratio S_m of the iron scrap is greater than or equal to 100 (step S107). When determining that the melting ratio S_m of the iron scrap is greater than or equal to 100 (Yes in step S107), the computing unit 38 determines that the iron scrap has completely melted and ends the present process. On the other hand, when determining that the melting ratio S_m of the iron scrap is less than 100 (No in step S107), the computing unit 38 returns the process to step S101, and performs steps S101 to S107 again to calculate the melting ratio S of the iron scrap after the calculation time interval Δt (in seconds). By thus repeatedly performing steps S101 to S107, the cold-iron-source melting ratio estimating method according to the present embodiment can calculate the moment-by-moment melting ratio S_m of the iron scrap until the iron scrap completely melts in the preliminary dephosphorization of the pig iron 11.

Examples

[0075] Examples will now be described. In Examples, a square pure iron sample (100 mm × 100 mm × 50 mm) simulating a cold iron source (iron scrap) was immersed 80 mm in 500 kg of molten iron produced using a cylindrical atmospheric furnace with an inside diameter of 430 mm, and the melting ratio of the square pure iron sample after a predetermined time period was estimated using the cold-iron-source melting ratio estimating method according to the present embodiment. After being immersed in the molten iron for the predetermined time period, the square pure iron sample was retrieved and subjected to air cooling. The melting ratio of the square pure iron sample was then actually measured using equation (26) described below.

[Math 10]

$$S_p = \frac{L_{S0} - L_S}{L_{S0}} \times 100 \cdot \cdot \cdot \quad (26)$$

[0076] Here, S_p is the melting ratio (% by mass) of the square pure iron sample, and L_{S0} and L_S are the thicknesses (mm) of the square pure iron sample before and after the immersion, respectively.

[0077] To measure the temperature of the molten iron and the carbon concentration in the molten iron, temperature measurement was performed with an immersion thermocouple and a molten iron sample for chemical analysis was taken, before and after immersion of the square pure iron sample in the molten iron.

[Example 1]

[0078] In Example 1, the melting ratio of the square pure iron sample was estimated by the cold-iron-source melting ratio estimating method according to the present embodiment when the square pure iron sample was preheated at 1200°C and when it was not preheated. Conditions of Example 1 are shown in Table 2 below.

[Table 2]

Item	Unit	Inventive Example 1	Inventive Example 2
Initial Temperature of Molten Iron	°C	1555	
Initial Carbon Concentration in Molten Iron	% by mass	0.05	
Temperature of Iron Sample	°C	25	1200
Initial Carbon Concentration in Iron Sample	% by mass	0.05	
Initial Thickness of Iron Sample	mm	50	

(continued)

Item	Unit	Inventive Example 1	Inventive Example 2
Bottom-Blowing Stirring Power	W/ton	126	

[0079] Fig. 4 is a graph illustrating results of estimation and actual measurement of the melting ratio of the square pure iron sample in Example 1. In Fig. 4, the vertical axis represents the melting ratio (% by mass) of the square pure iron sample and the horizontal axis represents the melting time (in seconds). In Fig. 4, each profile represents a melting ratio estimated by the cold-iron-source melting ratio estimating method, and each plot represents an actual measured value of the melting ratio (% by mass) of the square pure iron sample retrieved after immersion and subjected to air cooling. The actual measured value was calculated using equation (26) described above.

[0080] As illustrated in Fig. 4, the estimated value of the melting ratio substantially agreed with the experimental value regardless of whether the square pure iron sample was preheated. This result confirmed that by using the cold-iron-source melting ratio estimating method according to the present embodiment, the melting ratio of the cold iron source can be estimated with high accuracy.

[Example 2]

[0081] In Example 2, the melting ratio of the square pure iron sample using molten iron whose initial temperature was varied in the range of 1430°C to 1610°C was estimated by the cold-iron-source melting ratio estimating method according to the present embodiment. Conditions of Example 2 are shown in Table 3 below.

[Table 3]

Item	Unit	Inventive Example 11	Inventive Example 12	Inventive Example 13	Inventive Example 14	Inventive Example 15	Inventive Example 16
Initial Temperature of Molten Iron	°C	1430	1470	1510	1540	1580	1610
Initial Carbon Concentration in Molten Iron	% by mass	3.0-3.1					
Temperature of Iron Sample	°C	25					
Initial Carbon Concentration in Iron Sample	% by mass	0.05					
Initial Thickness of Iron Sample	mm	50					
Bottom-Blowing Stirring Power	W/ton	100					

[0082] Fig. 5 is a graph illustrating results of estimation and actual measurement of the melting ratio of the square pure iron sample in Example 2. In Fig. 5, the vertical axis represents the melting ratio (% by mass) of the square pure iron sample and the horizontal axis represents the melting time (in seconds). In Fig. 5, again, each profile represents a melting ratio estimated by the cold-iron-source melting ratio estimating method, and each plot represents an actual measured value of the melting ratio (% by mass) of the square pure iron sample retrieved after immersion and subjected to air cooling. The actual measured value was calculated using equation (26) described above.

[0083] As illustrated in Fig. 5, the estimated value of the melting ratio substantially agreed with the experimental value under conditions of Inventive Examples 11 to 16 where the initial temperature of the molten iron was varied. This result confirmed that by using the cold-iron-source melting ratio estimating method according to the present embodiment, the melting ratio of the cold iron source can be estimated with high accuracy.

[Example 3]

[0084] Example 3 compared melting ratios between the case where the melting ratio of the cold iron source was estimated from the first melting rate derived from equation (13) or the second melting rate derived from equation (14), and the case where the melting ratio of the cold iron source was estimated from the melting rate determined by proportionally distributing the first melting rate derived from equation (13) and the second melting rate derived from equation (14). Conditions of Example 3 are shown in Table 4 below.

[Table 4]

Item	Unit	Inventive Example 31
Initial Temperature of Molten Iron	°C	1450
Initial Carbon Concentration in Molten Iron	% by mass	4.3
Temperature of Iron Sample	°C	25
Initial Carbon Concentration in Iron Sample	% by mass	0.05
Initial Thickness of Iron Sample	mm	50
Bottom-Blowing Stirring Power	W/ton	116

[0085] Fig. 6 is a graph illustrating results of estimation and actual measurement of the melting ratio of the square pure iron sample in Example 3. In Fig. 6, the vertical axis represents the melting ratio (% by mass) of the square pure iron sample and the horizontal axis represents the melting time (in seconds). In Fig. 6, the profile indicated by a solid line represents a melting ratio estimated by the cold-iron-source melting ratio estimating method, and the profile indicated by a broken line represents a melting ratio estimated using only equation (13) or equation (14). Each circular plot represents an actual measured value of the melting ratio (% by mass) of the square pure iron sample retrieved after immersion and subjected to air cooling. The actual measured value was calculated using equation (26) described above.

[0086] Fig. 6 demonstrates that, in Inventive Example 31 where the melting ratio of the cold iron source was estimated from the melting rate determined by proportionally distributing the first melting rate and the second melting rate when at least one of inequalities (1) and (2) was satisfied, the estimated value substantially agreed with the experimental value. However, even in the case of satisfying at least one of inequalities (1) and (2) described above, when the melting ratio of the cold iron source was estimated from the melting rate derived only from equation (13) or equation (14), the estimated value did not agree with the experimental value. These results confirmed that to estimate the melting ratio of the cold iron source with high accuracy, it is important to determine an appropriate proportional distribution ratio and proportionally distributing the first melting rate derived from the heat transfer balance equation and the second melting rate derived from the carbon mass balance equation.

Reference Signs List

[0087]

- 10 converter-type refining furnace
- 11 pig iron
- 13 stirring gas
- 14 top blowing lance
- 20 converter-type refining furnace control apparatus
- 22 process computer
- 24 operation control computer
- 30 cold-iron-source melting ratio estimating device
- 32 controller
- 34 storage unit
- 36 acquiring unit
- 38 computing unit
- 40 output unit
- 50 operator

Claims

1. A cold-iron-source melting ratio estimating device configured to estimate a melting ratio of a cold iron source in refining of molten iron using the cold iron source as a raw material, the device comprising:

an acquiring unit configured to acquire in-furnace information including information about the molten iron and the cold iron source;
 a computing unit configured to calculate, using the in-furnace information, an interfacial carbon concentration between the cold iron source and the molten iron, a melting rate of the cold iron source, and a melting ratio of the cold iron source; and
 an output unit configured to output the melting ratio,
 wherein when the interfacial carbon concentration satisfies at least one of inequalities (1) and (2) described below, the computing unit calculates, using an interfacial carbon concentration calculated in the previous step, a first melting rate from a heat transfer balance equation and a second melting rate from a carbon mass balance equation, respectively, and calculates the melting rate of the cold iron source by proportionally distributing the first melting rate and the second melting rate; and
 when the interfacial carbon concentration satisfies neither of inequalities (1) and (2) described below, the computing unit calculates the first melting rate or the second melting rate using the interfacial carbon concentration, and determines the calculated first or second melting rate to be the melting rate of the cold iron source:

$$C_i > C \quad \cdots \quad (1)$$

$$C_i > C_{i, t-1} \quad \cdots \quad (2),$$

where, in inequalities (1) and (2) described above, C is a carbon concentration (% by mass) in molten iron, C_i is an interfacial carbon concentration (% by mass), and $C_{i, t-1}$ is an interfacial carbon concentration (% by mass) calculated in the previous step.

2. The cold-iron-source melting ratio estimating device according to Claim 1, wherein when a carbon concentration in the cold iron source is lower than a carbon concentration in the molten iron, the computing unit determines a proportional distribution ratio for proportionally distributing the first melting rate and the second melting rate on the basis of a temperature of the molten iron, the carbon concentration in the molten iron, and the carbon concentration in the cold iron source.

3. The cold-iron-source melting ratio estimating device according to Claim 1 or Claim 2, wherein the computing unit estimates a moment-by-moment melting ratio of the cold iron source by repeatedly calculating the interfacial carbon concentration, the melting rate of the cold iron source, and the melting ratio of the cold iron source.

4. A molten iron refining method comprising:

estimating a melting ratio of the cold iron source at an end of the refining by using the cold-iron-source melting ratio estimating device according to Claim 1 or Claim 2; and
 performing, when a ratio of an unmolten cold iron source calculated from the melting ratio at the end of the refining exceeds 5% by mass, at least one of adding a heating material and extending a molten iron treatment.

5. A molten iron refining method comprising:

estimating a melting ratio of the cold iron source at an end of the refining by using the cold-iron-source melting ratio estimating device according to Claim 3; and
 performing, when a ratio of an unmolten cold iron source calculated from the melting ratio at the end of the refining exceeds 5% by mass, at least one of adding a heating material and extending a molten iron treatment.

6. A cold-iron-source melting ratio estimating method for estimating a melting ratio of a cold iron source in refining of molten iron using the cold iron source as a raw material, the method comprising:

an acquiring step of acquiring in-furnace information including information about the molten iron and the cold iron source;

a computing step of calculating, using the in-furnace information, an interfacial carbon concentration between the cold iron source and the molten iron, a melting rate of the cold iron source, and a melting ratio of the cold iron source; and

an outputting step of outputting the melting ratio,

wherein when the interfacial carbon concentration satisfies at least one of inequalities (1) and (2) described below, the computing step calculates, using an interfacial carbon concentration calculated in the previous step, a first melting rate from a heat transfer balance equation and a second melting rate from a carbon mass balance equation, respectively, and calculates the melting rate of the cold iron source by proportionally distributing the first melting rate and the second melting rate; and

when the interfacial carbon concentration satisfies neither of inequalities (1) and (2) described below, the computing step calculates the first melting rate or the second melting rate using the interfacial carbon concentration, and determines the calculated first or second melting rate to be the melting rate of the cold iron source:

$$C_i > C \quad \cdots \quad (1)$$

$$C_i > C_{i, t-1} \quad \cdots \quad (2)$$

where, in inequalities (1) and (2) described above, C is a carbon concentration (% by mass) in molten iron, C_i is an interfacial carbon concentration (% by mass), and $C_{i, t-1}$ is an interfacial carbon concentration (% by mass) calculated in the previous step.

7. The cold-iron-source melting ratio estimating method according to Claim 6, wherein when a carbon concentration in the cold iron source is lower than a carbon concentration in the molten iron, the computing step determines a proportional distribution ratio for proportionally distributing the first melting rate and the second melting rate on the basis of a temperature of the molten iron, the carbon concentration in the molten iron, and the carbon concentration in the cold iron source.

8. The cold-iron-source melting ratio estimating method according to Claim 6 or Claim 7, wherein the computing step estimates a moment-by-moment melting ratio of the cold iron source by repeatedly calculating the interfacial carbon concentration, the melting rate of the cold iron source, and the melting ratio of the cold iron source.

9. A molten iron refining method comprising:

estimating a melting ratio of the cold iron source at an end of the refining by using the cold-iron-source melting ratio estimating method according to Claim 6 or Claim 7; and

performing, when a ratio of an unmolten cold iron source calculated from the melting ratio at the end of the refining exceeds 5% by mass, at least one of adding a heating material and extending a molten iron treatment.

10. A molten iron refining method comprising:

estimating a melting ratio of the cold iron source at an end of the refining by using the cold-iron-source melting ratio estimating method according to Claim 8; and

performing, when a ratio of an unmolten cold iron source calculated from the melting ratio at the end of the refining exceeds 5% by mass, at least one of adding a heating material and extending a molten iron treatment.

FIG. 1

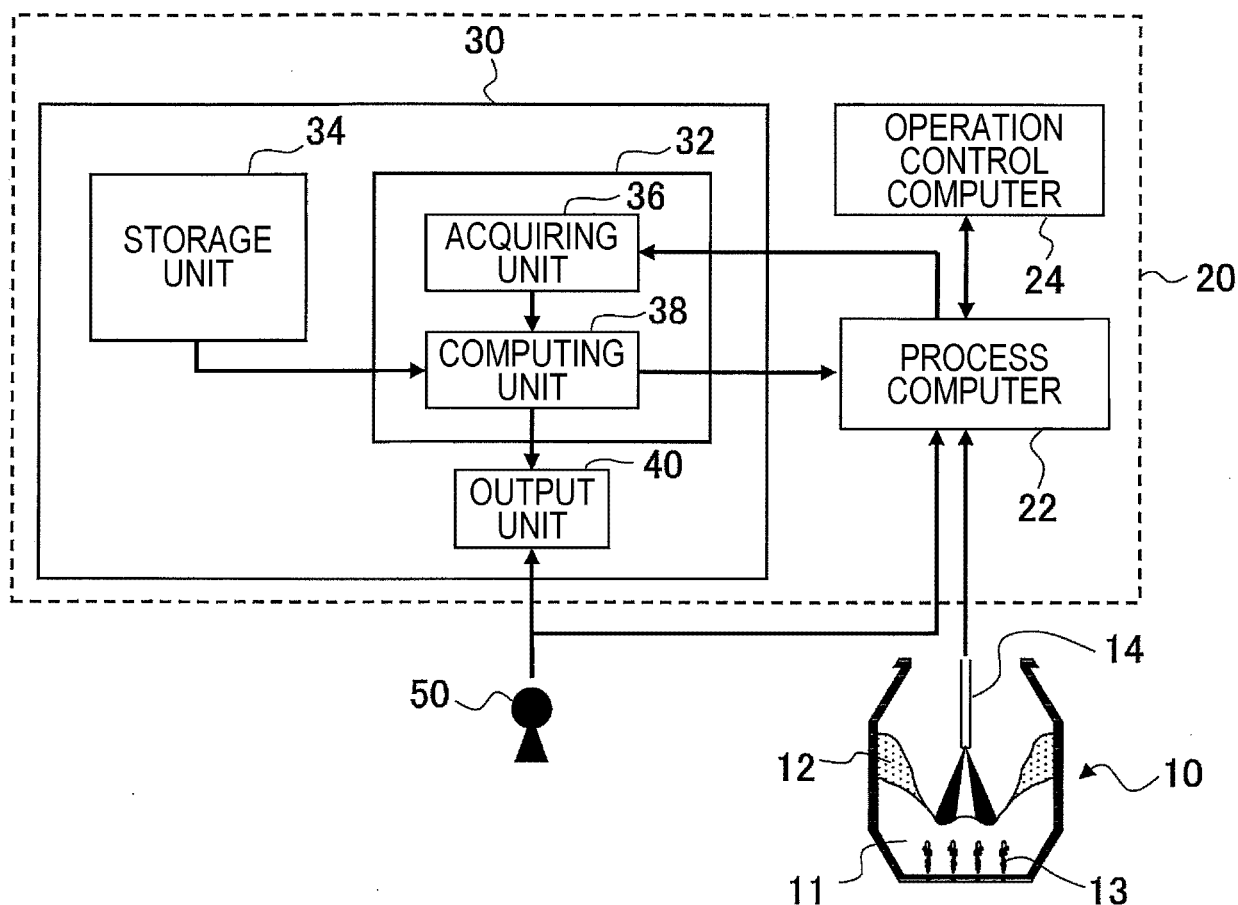


FIG. 2

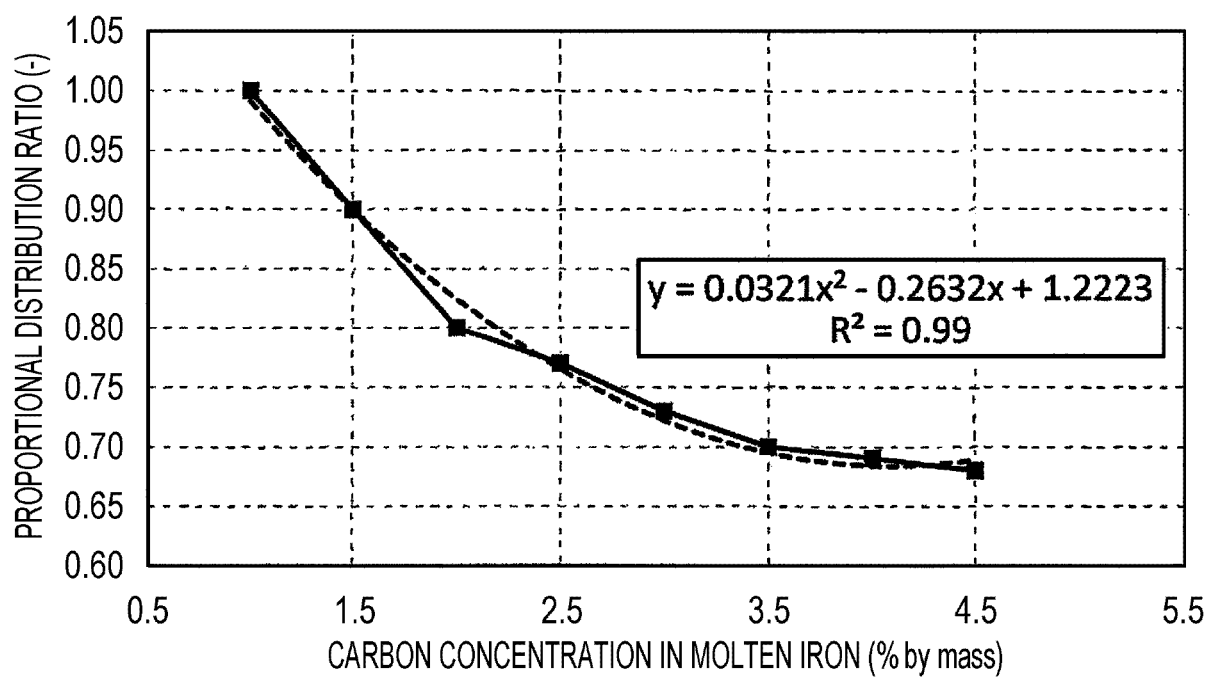


FIG. 3

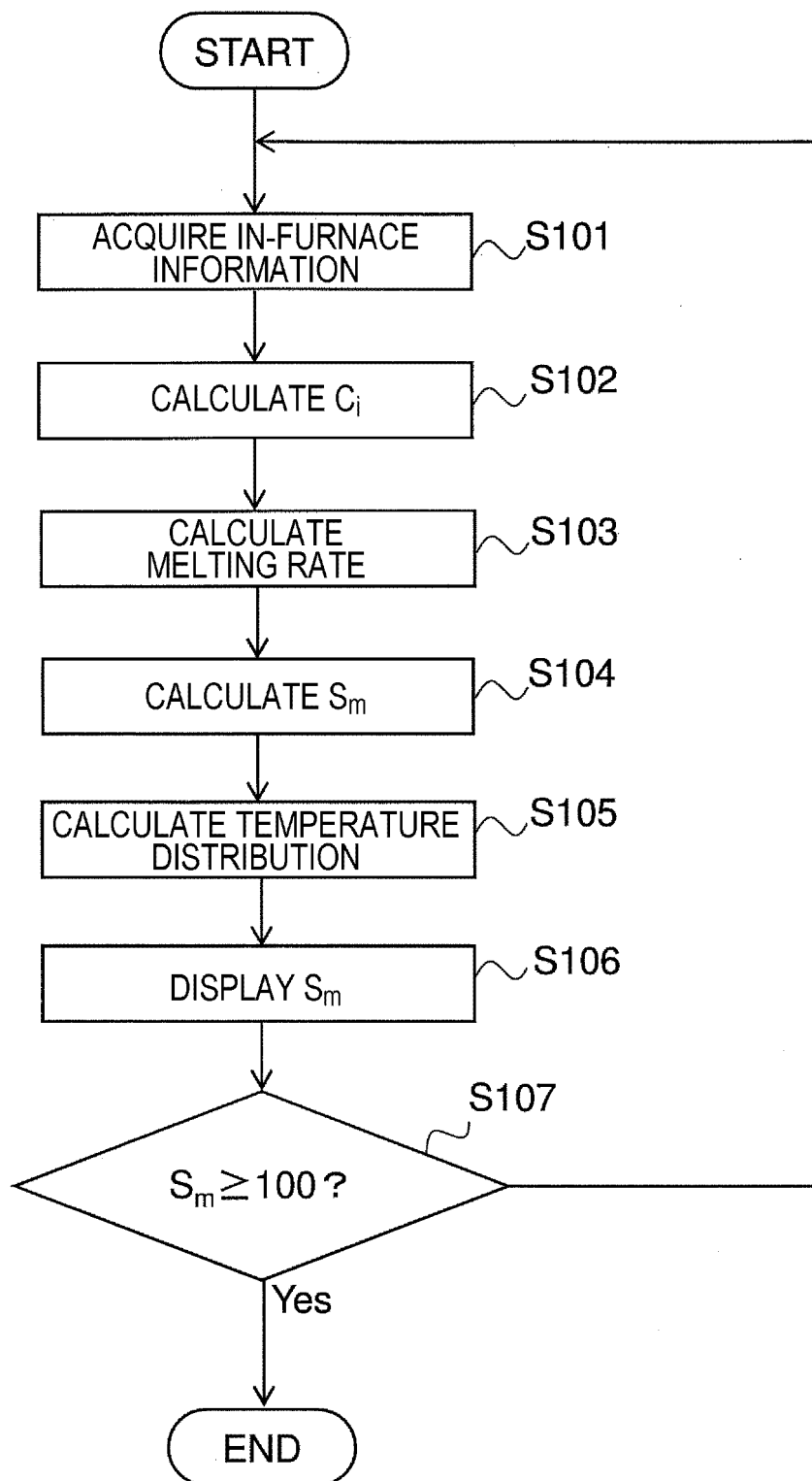


FIG. 4

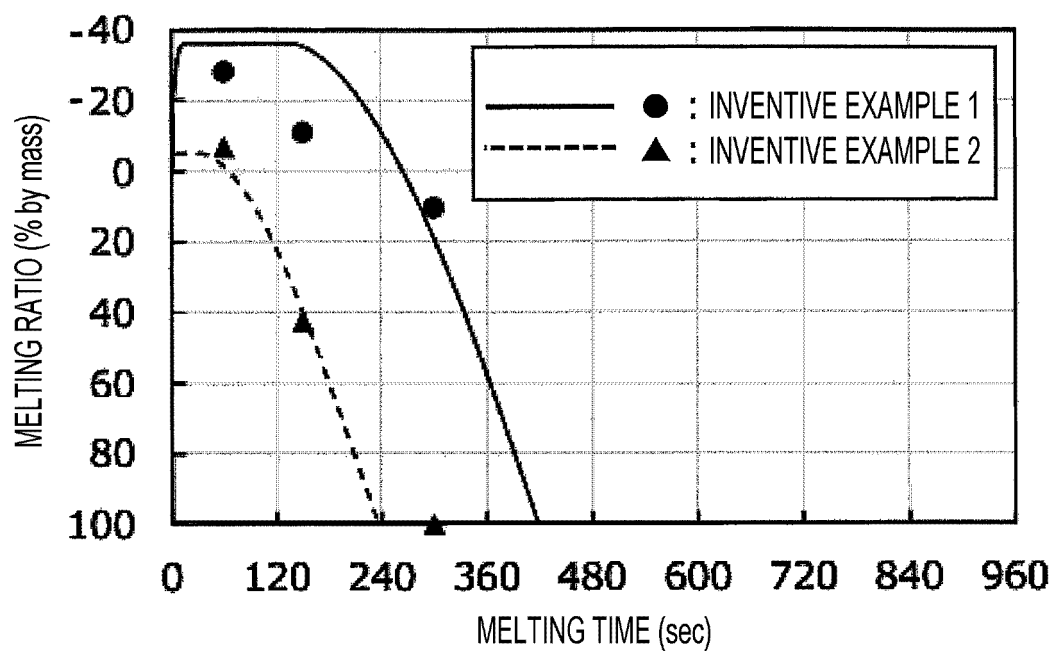


FIG. 5

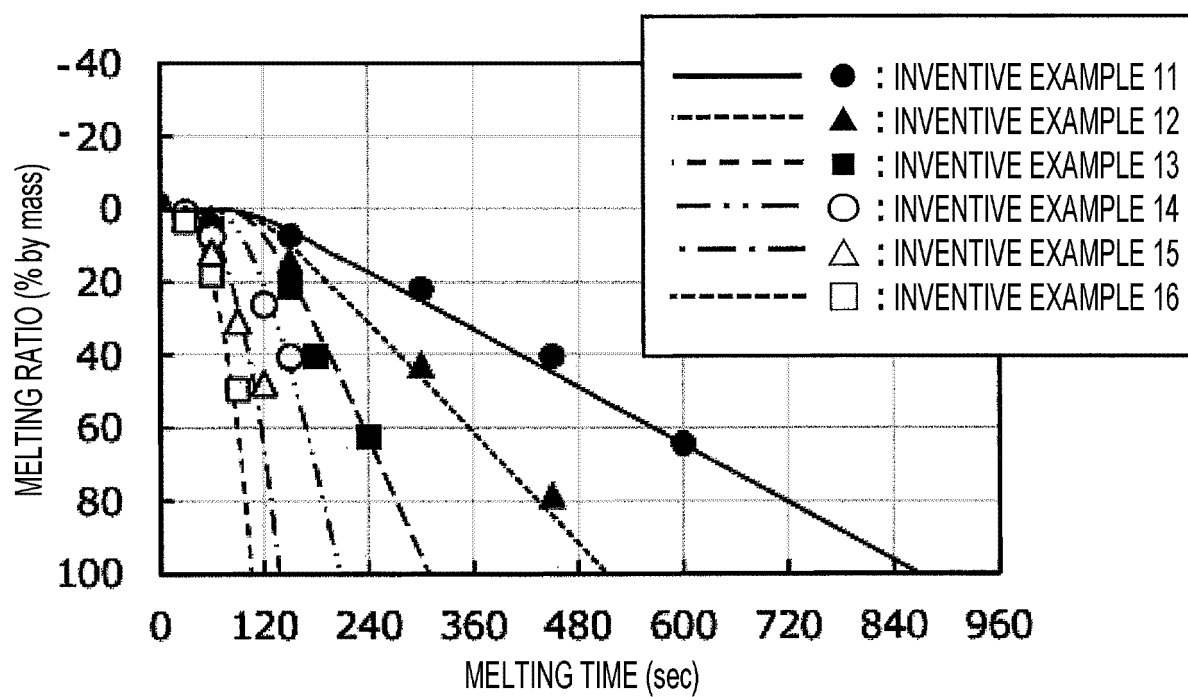
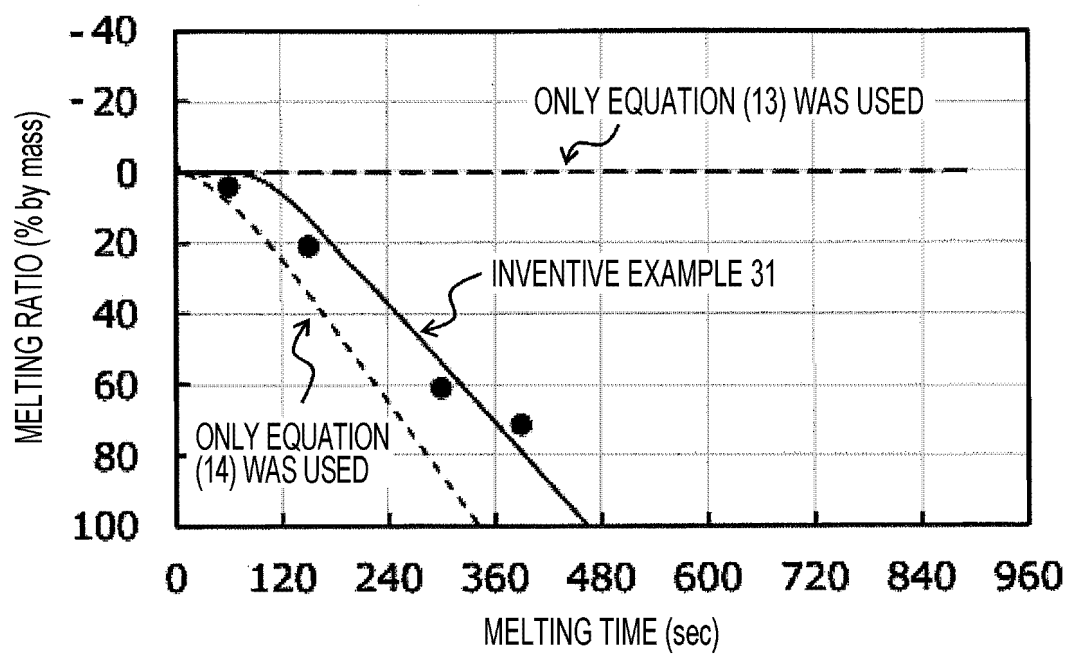


FIG. 6



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2023/021995

A. CLASSIFICATION OF SUBJECT MATTER

C21C 5/28(2006.01)i; C21C 5/30(2006.01)i; C22B 9/16(2006.01)i

FI: C21C5/28 Z; C21C5/30 Z; C22B9/16

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)

C21C5/28; C21C5/30; C22B9/16

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 2009-256716 A (NIPPON STEEL CORP.) 05 November 2009 (2009-11-05) entire text	1-10
A	JP 04-000313 A (NIPPON STEEL CORP.) 06 January 1992 (1992-01-06) entire text	1-10
A	JP 2016-132809 A (NIPPON STEEL & SUMITOMO METAL CORP.) 25 July 2016 (2016-07-25) entire text	1-10
A	JP 2005-206901 A (KOBELITE, LTD.) 04 August 2005 (2005-08-04) entire text	1-10

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

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"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

06 July 2023

Date of mailing of the international search report

18 July 2023

Name and mailing address of the ISA/JP

Japan Patent Office (ISA/JP)
 3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915
 Japan

Authorized officer

Telephone No.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2023/021995

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP	2009-256716	A	05 November 2009	(Family: none)	
JP	04-000313	A	06 January 1992	(Family: none)	
JP	2016-132809	A	25 July 2016	(Family: none)	
JP	2005-206901	A	04 August 2005	(Family: none)	

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- JP 8003614 A [0008]

Non-patent literature cited in the description

- **MASAHIRO KAWAKAMI**. Heat and Mass Transfer Analysis of Scrap Melting in Steel Bath. *Tetsu-to-Hagané*, 1999, vol. 85, 658-665 [0009]
- **KOHICHI ISOBE**. Analysis of the Scrap Melting Rate in High Carbon Molten Iron. *Tetsu-to-Hagané*, 1990, vol. 76, 2033-2040 [0009]
- **H. GAYE ; M. WANIN ; P. GUGLIERMINA ; P. SCHITTLY**. *Steelmaking Conf. Proc., ISS, Detroit, MI*, 1985, vol. 91 [0044]