(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 4 477 763 A1

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

(43) Date of publication:
18.12.2024 Bulletin 2024/51

(21) Application number: **22937526.6**

(22) Date of filing: **16.12.2022**

(51) International Patent Classification (IPC):
C21B 5/00 *(2006.01)*

(52) Cooperative Patent Classification (CPC):
C21B 5/00

(86) International application number:
PCT/JP2022/046306

(87) International publication number:
WO 2023/199551 (19.10.2023 Gazette 2023/42)

(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

(30) Priority: **11.04.2022 JP 2022064978**

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

(72) Inventors:
- **SAWAKI Naomi**
  Tokyo 100-0011 (JP)
- **KAWASHIRI Yuki**
  Tokyo 100-0011 (JP)

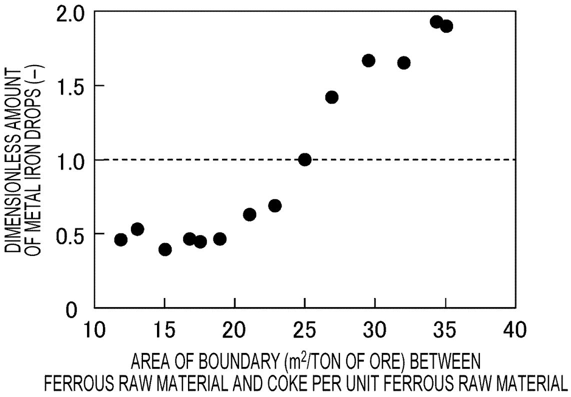
(74) Representative: **Hoffmann Eitle**
Patent- und Rechtsanwälte PartmbB
Arabellastraße 30
81925 München (DE)

(54) BLAST FURNACE OPERATION METHOD

(57) In a blast furnace operation that generates a high-concentration reducing gas in a raceway in the furnace, a blast furnace operation method is provided that can maintain appropriate liquid permeability of metal iron through the cohesive zone and the dripping zone in the blast furnace and can control the gas permeability in the blast furnace within an operable range.

A blast furnace operation method according to the present invention is a method of operating a blast furnace while charging a ferrous raw material and coke from a blast furnace top, and injecting from a blast furnace tuyere a gas that generates a high-concentration reducing gas in a raceway in the blast furnace, and the method includes controlling the area of boundary between the ferrous raw material and the coke per unit ferrous raw material to a predetermined range. In this case, the area of boundary per unit ferrous raw material is preferably controlled to 25 m^2/ton of ore or more.

FIG. 4



EP 4 477 763 A1

Processed by Luminess, 75001 PARIS (FR)

Description

Technical Field

[0001] The present invention relates to a method of operating a blast furnace while generating a high-concentration reducing gas in a raceway in the blast furnace, and more particularly to a blast furnace operation method that enhances the liquid permeability of metal iron through a cohesive zone and a dripping zone in a blast furnace, and the gas permeability through the blast furnace.

Background Art

[0002] In recent years, there have been growing efforts to reduce the emissions of CO_2 gas (carbon dioxide gas) that is one of the greenhouse gases. Blast furnace iron manufacturing involves carbon materials as reducing agents and thus generates large amounts of CO_2 gas. Thus, the steel industry is one of the major CO_2 emitting industries and must respond to the social demands for cutting the CO_2 gas emissions. Specifically, it is urgent to further decrease the ratio of coal-derived reducing agents in the blast furnace operation. The ratio of coal-derived reducing agents is the total mass of coal-derived coke and coal-derived reducing gas required to produce 1 ton of molten pig iron.

[0003] Reducing agents have a role to generate heat in the furnace and thereby raise the temperature of the burden, and a role to reduce the ferrous raw material in the furnace, namely, iron ore, sintered iron ore, and iron ore pellets. In order to lower the reducing agent ratio and thereby to cut the CO_2 emissions, it is necessary to increase the reduction efficiency of the reducing agent while maintaining the amount of heat in the furnace.

[0004] Hydrogen has attracted attention as a reducing agent for the purpose of cutting CO_2 emissions. The reduction of iron ore with hydrogen is an endothermic reaction, but the endothermic amount is smaller than that in the direct reduction reaction (reaction formula: $FeO + C \rightarrow Fe + CO$). Furthermore, hydrogen outperforms CO gas in reduction rate. Therefore, the CO_2 emissions can be reduced and the reduction efficiency can be enhanced at the same time by the blowing of hydrogen-based gas into the blast furnace.

[0005] Stable operation of a blast furnace critically relies on the gas permeability through the blast furnace cohesive zone in which the ferrous raw material is fused. However, the gas permeability in a blast furnace is not clearly understood in blast furnace operations where a high-concentration reducing gas is generated in a raceway in the blast furnace, and in blast furnace operations in which the reducing gas concentration in the furnace is higher than in the conventional operation and the reduction reaction rate is high.

[0006] Hydrogen reduces the ferrous raw material with a higher reduction ratio than CO gas. Thus, raw material charging conditions that ensure appropriate liquid permeability of metal iron (metal iron produced by reduction) and appropriate gas permeability need to be established for blast furnace operation that involves a high reduction ratio.

[0007] Conventional techniques for solving problems similar to those described above are disclosed in Patent Literatures 1 and 2.

[0008] Patent Literature 1 discloses a burden distribution controlling method that achieves stable blast furnace operation by reliably and accurately controlling the charging pattern of the burden along the radial direction of the furnace throat so that the ore layer/coke layer relative thickness ratio in a peripheral region in the blast furnace will be 0.50 to 0.70.

[0009] In a blast furnace operation in which 180 kg or more of pulverized coal per ton of molten pig iron is injected from the tuyere, Patent Literature 2 discloses a blast furnace operation method that charges coke and iron ore from the top of the furnace so that the ratio of the coke layer thickness Lc to the burden layer thickness that combines the coke layer thickness Lc and the ore layer thickness Lo will satisfy predetermined values in regions divided along the furnace radial direction. According to Patent Literature 2, the technique can decrease the pressure loss in the upper part of the burden layer in the blast furnace, can maintain good gas permeability in the furnace, and enables stable operation with a high volume of pulverized coal injection.

Citation List

Patent Literature

[0010]

PTL 1: Japanese Unexamined Patent Application Publication No. 2000-256712
PTL 2: Japanese Unexamined Patent Application Publication No. 2002-129211

Summary of Invention

Technical Problem

[0011] However, these conventional techniques are directed to operation under conditions where the reduction ratio of the ferrous raw material is low. When the reduction ratio of the ferrous raw material is increased by generating a high-concentration reducing gas in a raceway in the blast furnace, the liquid permeability of metal iron is deteriorated and the gas permeability through the cohesive zone is lowered. Unfortunately, the above conventional techniques are not effective for solving such a blast furnace operation problem.

[0012] Specifically, the ferrous raw material is reduced in a promoted manner from a low temperature compared to the conventional operation and reaches an increased reduction ratio when a high-concentration reducing gas is generated in a raceway in the furnace within the range of region A in Fig. 1 (Fig. 1 will be described later) (the range including H_2 gas = 0 to 100 vol%, N_2 gas = 0 to 71 vol%, and CO gas = 0 to 100 vol%). Thus, more metal iron is produced in the blast furnace.

[0013] The melting point of iron (Fe) is 1538°C and is higher than the melting point of FeO, 1377°C. For this reason, an operation that charges raw materials in the conventional manner encounters a problem in which the liquid permeability of metal iron is low and the metal iron that should drop into the hearth remains in voids of the coke layers. This increases the gas permeability resistance in the blast furnace and gives rise to a risk of gas channeling.

[0014] The present invention has been made in view of the circumstances discussed above. In a blast furnace operation that generates a high-concentration reducing gas in a raceway in the furnace, an object of the present invention is to provide a blast furnace operation method that can maintain appropriate liquid permeability of metal iron through the cohesive zone and the dripping zone in the blast furnace and can control the gas permeability in the blast furnace within an operable range.

Solution to Problem

[0015] The present inventors carried out extensive studies directed to solving the problems described above. The finding is that in a blast furnace operation that generates a high-concentration reducing gas in a raceway in the blast furnace, the area of boundary between the ferrous raw material and the coke is controlled so as to increase the carburized area of the coke carbon with respect to the metal iron produced in the furnace, and thereby lowering of the melting point of the metal iron by the carburization is promoted. The present inventors have found that the above control allows for good liquid permeability of metal iron through the cohesive zone and the dripping zone in the blast furnace and also ensures good gas permeability in the blast furnace. The present invention has been completed based on the above findings. A gist of the present invention is as follows.

[0016]

[1] A blast furnace operation method of operating a blast furnace while alternately charging a ferrous raw material and coke from a blast furnace top, and injecting from a blast furnace tuyere a gas that generates a high-concentration reducing gas in a raceway in the blast furnace, the method including controlling the area of boundary between the ferrous raw material and the coke per unit ferrous raw material to a predetermined range.

[2] The blast furnace operation method according to [1], wherein the area of boundary per unit ferrous raw material is the total of the area of boundary between a ferrous raw material layer and a coke layer per unit ferrous raw material plus the area of boundary between the ferrous raw material and coke particles mixed in the ferrous raw material layer.

[3] The blast furnace operation method according to [2], wherein the area of boundary per unit ferrous raw material is controlled to 25 m^2/ton of ore or more.

[4] The blast furnace operation method according to [1], wherein the high-concentration reducing gas, when expressed by bosh gas composition, is composed of H_2 gas, N_2 gas, and CO gas; has a composition of H_2 gas, N_2 gas, and CO gas within a region enclosed by four points in a H_2 gas-N_2 gas-CO gas ternary diagram wherein the four points are a point at H_2 gas: 0 vol%, N_2 gas: 0 vol%, and CO gas: 100 vol%, a point at H_2 gas: 100 vol%, N_2 gas: 0 vol%, and CO gas: 0 vol%, a point at H_2 gas: 29 vol%, N_2 gas: 71 vol%, and CO gas: 0 vol%, and a point at H_2 gas: 0 vol%, N_2 gas: 37 vol%, and CO gas: 63 vol%; and includes H_2 gas in the range of 0 to 100 vol%, N_2 gas in the range of 0 to 71 vol%, and CO gas in the range of 0 to 100 vol%.

[5] The blast furnace operation method according to [2], wherein the high-concentration reducing gas, when expressed by bosh gas composition, is composed of H_2 gas, N_2 gas, and CO gas; has a composition of H_2 gas, N_2 gas, and CO gas within a region enclosed by four points in a H_2 gas-N_2 gas-CO gas ternary diagram wherein the four points are a point at H_2 gas: 0 vol%, N_2 gas: 0 vol%, and CO gas: 100 vol%, a point at H_2 gas: 100 vol%, N_2 gas: 0 vol%, and CO gas: 0 vol%, a point at H_2 gas: 29 vol%, N_2 gas: 71 vol%, and CO gas: 0 vol%, and a point at H_2 gas: 0 vol%, N_2 gas: 37 vol%, and CO gas: 63 vol%; and includes H_2 gas in the range of 0 to 100 vol%, N_2 gas in the range of 0 to 71 vol%, and CO gas in the range of 0 to 100 vol%.

[6] The blast furnace operation method according to [3], wherein the high-concentration reducing gas, when expressed by bosh gas composition, is composed of H_2 gas, N_2 gas, and CO gas; has a composition of H_2 gas, N_2 gas, and CO gas within a region enclosed by four points in a H_2 gas-N_2 gas-CO gas ternary diagram wherein the four points are a point at H_2 gas: 0 vol%, N_2 gas: 0 vol%, and CO gas: 100 vol%, a point at H_2 gas: 100 vol%, N_2 gas: 0 vol%, and CO gas: 0 vol%, a point at H_2 gas: 29 vol%, N_2 gas: 71 vol%, and CO gas: 0 vol%, and a point at H_2 gas: 0 vol%, N_2 gas: 37 vol%, and CO gas: 63 vol%; and includes H_2 gas in the range of 0 to 100 vol%, N_2 gas in the range of 0 to 71 vol%, and CO gas in the range of 0 to 100 vol%.

[7] The blast furnace operation method according to any one of [1] to [6], wherein the volume of H_2 in the high-concentration reducing gas is in the range of 0 to 500 Nm^3/ton of molten pig iron.

Advantageous Effects of Invention

[0017] In a blast furnace operation that generates a high-concentration reducing gas in a raceway in the furnace, the present invention charges a ferrous raw material and coke from the furnace top while controlling the area of boundary between these materials per unit ferrous raw material to a predetermined range. This control promotes the carburization of metal iron that is produced and lowers the melting point of the metal iron, thus allowing the metal iron to maintain appropriate liquid permeability through the cohesive zone and the dripping zone in the blast furnace. As a result, the gas permeability in the blast furnace can be maintained in an operable range, and the blast furnace can be operated stably.

Brief Description of Drawings

[0018]

[Fig. 1] Fig. 1 is a H_2 gas-N_2 gas-CO gas ternary diagram that illustrates the range of the bosh gas composition of a high-concentration reducing gas generated in a raceway in the furnace in a blast furnace operation method according to an embodiment.

[Fig. 2] Fig. 2 is a view schematically illustrating the shapes of ferrous raw material layers and coke layers in a blast furnace.

[Fig. 3] Fig. 3(A) is a view schematically illustrating a ferrous raw material layer and coke particles mixed in the ferrous raw material layer, and Fig. 3(B) is a view schematically illustrating the shape of a coke particle mixed in the ferrous raw material layer.

[Fig. 4] Fig. 4 is a graph illustrating a relationship between the amount of metal iron drops and the area of boundary S_{unit} between a ferrous raw material and coke per unit ferrous raw material.

[Fig. 5] Fig. 5 is a graph illustrating a relationship between the gas permeability resistance index KS and the area of boundary S_{unit} between a ferrous raw material and coke per unit ferrous raw material.

Description of Embodiments

[0019] Hereinafter, an embodiment of the present invention will be described in detail. A blast furnace operation method according to the present embodiment is a method of operating a blast furnace in such a manner that a ferrous raw material and coke are alternately charged from a blast furnace top into the blast furnace to form alternate layers, and a gas is injected from a tuyere disposed at a lower position of the blast furnace and the gas that has been injected from the tuyere into the blast furnace generates a high-concentration reducing gas in the raceway in the blast furnace. For example, the ferrous raw material includes iron ore, sintered iron ore, iron ore pellets, reduced iron, and iron scraps. The types of the ferrous raw material and the coke that are used are not particularly limited, and any ferrous raw materials and cokes used in the conventional blast furnace operations may be suitably used in the present invention.

[0020] The gas for generating a high-concentration reducing gas contains a reductive component that reduces the ferrous raw material in the blast furnace. Here, the reductive component that reduces the ferrous raw material in the blast furnace may be CO gas, H_2 gas, or a hydrocarbon gas capable of reducing the ferrous raw material by itself, or may be CO_2 gas, H_2O gas, or the like that generates a reducing gas through, for example, the reaction with the coke or the decomposition reaction.

[0021] Fig. 1 is a H_2 gas-N_2 gas-CO gas ternary diagram that illustrates the range of the gas composition of a high-concentration reducing gas generated in a raceway in the furnace in the blast furnace operation method according to the present embodiment. The high-concentration reducing gas in the present embodiment is a reducing gas that reduces the ferrous raw material with an average reduction ratio of 80% or more when the high-concentration reducing gas is allowed to act on the material at 900°C for 180 minutes. This reducing gas, when expressed by bosh gas composition, is composed of H_2 gas, N_2 gas, and CO gas; has a composition of H_2 gas, N_2 gas, and CO gas (with the proviso that H_2 gas + N_2 gas + CO gas = 100 vol%) within the shaded region A in Fig. 1 (the range of the operation according to the present invention); and includes H_2 gas in the range of 0 to 100 vol%, N_2 gas in the range of 0 to 71 vol%, and CO gas in the range of 0 to 100 vol%.

[0022] In the H_2 gas-N_2 gas-CO gas ternary diagram, the region A is enclosed by four points including point O (H_2 gas: 0 vol%, N_2 gas: 0 vol%, CO gas: 100 vol%), point P (H_2 gas: 100 vol%, N_2 gas: 0 vol%, CO gas: 0 vol%), point Q (H_2 gas: 29 vol%, N_2 gas: 71 vol%, CO gas: 0 vol%), and point R (H_2 gas: 0 vol%, N_2 gas: 37 vol%, CO gas: 63 vol%). As a comparison, Fig. 1 also illustrates the range of the gas composition in conventional general blast furnace operations.

[0023] In this region A, the average reduction ratio is 90% or more when the ferrous raw material is reduced at 900°C for 180 minutes in the region enclosed by four points including point O' (H_2 gas: 0 vol%, N_2 gas: 0 vol%, CO gas: 100 vol%), point P' (H_2 gas: 100 vol%, N_2 gas: 0 vol%, CO gas: 0 vol%), point Q' (H_2 gas: 43 vol%, N_2 gas: 57 vol%, CO gas: 0 vol%), and point R' (H_2 gas: 0 vol%, N_2 gas: 14 vol%, CO gas: 86 vol%). Thus, the amount of FeO in the slag components in the cohesive zone in the furnace is significantly low. When a high-concentration reducing gas falling in this composition range is generated in a raceway in the furnace, the control of the area of boundary between the ferrous raw material and the coke per unit ferrous raw material to the predetermined range produces greater effects by maintaining appropriate liquid permeability of the metal iron.

[0024] The present inventors conducted a test in which a high-concentration reducing gas was generated in a raceway in a 1/4 scale small test furnace simulating a blast furnace. In the test, the relationship was investigated between the area of boundary between the ferrous raw material and the coke in the cohesive zone and the dripping zone in the furnace, and the amount of metal iron drops (the metal produced by reduction). Here, the area of boundary between the ferrous raw material and the coke is the area of boundary S_{total} that combines the area of boundary S between a ferrous raw material layer and a coke layer, and the area of boundary S_{mix} between the ferrous raw material and the coke particles mixed in the ferrous raw material layer ($S_{total} = S + S_{mix}$).

[0025] Fig. 2 is a view schematically illustrating the shapes of the ferrous raw material layers and the coke layers in the furnace. As illustrated in Fig. 2, the observation confirmed that the ferrous raw material layers and the coke layers descended inside the blast furnace while remaining layered. In this case, the boundary between the ferrous raw material layer and the coke layer occurs between the lower face of the ferrous raw material layer and the upper face of the coke layer (boundary 1 in Fig. 2) and between the upper face of the ferrous raw material layer and the lower face of the coke layer (boundary 2 in Fig. 2). Assuming that the boundary 1 and the boundary 2 had the same area, the area of boundary S between the ferrous raw material layer and the coke layer was calculated using the equation (1) below.

[Math. 1]

$$S = 2 \times \pi \left(\frac{D}{2 \times \cos(\theta)} \right)^2 \quad \cdots (1)$$

[0026] In the equation (1), D is the furnace diameter (m) of the test furnace, θ is the inclination angle (°) of the burden in the furnace (the ferrous raw material layers and the coke layers) with respect to a horizontal line, and π is the circumference ratio. For the furnace diameter D, the furnace belly diameter obtained from the design drawing of the test furnace was used. For the inclination angle θ, a value measured at the lumpy zone in the furnace was used. When the boundary between the ferrous raw material layer and the coke layer cannot be approximated by a straight line, for example, the boundary in the radial direction is divided into multiple sections that can be each approximated by a straight line, and the inclination angles of the sections are measured and averaged to determine the inclination angle θ.

[0027] Fig. 3(A) is a view schematically illustrating the ferrous raw material layer and coke particles mixed in the ferrous raw material layer, and Fig. 3(B) is a view schematically illustrating the shape of a coke particle mixed in the ferrous raw material layer. The area of boundary S_{mix} between the ferrous raw material and the coke particles mixed in the ferrous raw material layer was calculated using the equations (2) and (3) below assuming that the coke particles mixed in the ferrous raw material layer were regular octahedrons as illustrated in Fig. 3(B).

[Math. 2]

$$S_{mix} = 2\sqrt{3}\, a^2 \times \frac{1000 W_c}{\rho_c \times \frac{\sqrt{2}}{3} a^3} \quad \cdots (2)$$

$$a = \frac{0.72 d}{2} \times \frac{6}{\sqrt{6}} \quad \cdots (3)$$

[0028] In the equations (2) and (3), a is the length (m) of one side of the regular octahedron; W_c is the mass (tons/charge) of the coke mixed per ferrous raw material layer in the furnace); ρ_c is the apparent density (kg/m^3) of the coke; and d is the particle size (m) of the coke that is mixed. The apparent density ρ_c of the coke was measured by the immersion method based on the mass per unit volume including voids in the particles. The particle size d of the coke mixed was the average particle size of the coke sampled from the mixed burden layer.

[0029] The area of boundary S_{unit} between the ferrous raw material and the coke per unit ferrous raw material is expressed by the equation (4) below.

[Math. 3]

$$S_{unit} = \frac{S_{total}}{W_{Iron}} = \frac{S + S_{mix}}{W_{Iron}} \quad \cdots (4)$$

[0030] In the equation (4), W_{Iron} is the mass (tons/charge) of the ferrous raw material per ferrous raw material layer in the furnace.

[0031] The area of boundary S_{unit} between the ferrous raw material and the coke per unit ferrous raw material is a quotient of the area of boundary S_{total} divided by W_{Iron}. The area of boundary S_{total} includes the area of boundary between the lower face of the ferrous raw material layer and the upper face of the coke layer, and the area of boundary between the upper face of the ferrous raw material layer and the lower face of the coke layer. Furthermore, the coke particles that are mixed into the ferrous raw material layer at the time of charging are regarded as regular octahedrons, and the surface area of the regular octahedrons corresponding to the number of the coke particles is calculated as the area of boundary between the ferrous raw material and the coke particles. This area of boundary is also included in the area of boundary S_{total}.

[0032] In the small test furnace, the raw materials were charged under conventional operation conditions while generating a high-concentration reducing gas in a raceway in the furnace. The area of boundary S_{unit} between the ferrous raw material and the coke per unit ferrous raw material was approximately 14 m^2/ton or ore. Under these raw material-charging conditions, the amount of melt drops in the cohesive zone decreased to about one-tenth of that in the conventional tests and the gas permeability was deteriorated to a level where stable test was no longer feasible. This indicates that the raw material-charging conditions require resetting to fit for a blast furnace operation that generates a high-concentration reducing gas in a raceway in the furnace.

[0033] Based on the knowledge that the enhancement in liquid permeability of metal iron critically relies on increasing the area of carburization on the metal iron produced by reduction in the blast furnace, a test was conducted in which a high-concentration reducing gas was generated in a raceway in the small test furnace while changing the area of boundary S_{unit} between the ferrous raw material and the coke per unit ferrous raw material. In the test, the area of boundary S_{unit} between the ferrous raw material and the coke per unit ferrous raw material was changed within the range of 12 to 35 m^2/ton of ore, and the influence of the area of boundary S_{unit} per unit ferrous raw material on the amount of metal iron drops and the gas permeability resistance index KS was studied.

[0034] The amount of metal iron drops was determined by recovering the melt that had dropped during the test after the experiment, separating the metal iron from the slag, and measuring the weight of the metal iron with a weighing machine. The gas permeability resistance index KS was determined as an integral value of gas permeability resistance K (1/m) calculated based on the pressure loss measured in a region inside the furnace where the temperature was 1000°C or above, and properties estimated from the operation conditions.

<Method of Calculating the Gas Permeability Resistance Index KS>

[0035] The gas permeability resistance K (1/m) is calculated from the equation (5) below.

$$K = (\Delta P/H)/(\rho_{gas}^{0.7} \times \mu_{gas}^{0.3} \times v_{gas}^{1.7}) \quad \cdots (5)$$

[0036] Here, ΔP is the pressure loss (Pa), H is the thickness (m) of the packed bed in the furnace, ρ_{gas} is the gas density (kg/m^3), μ_{gas} is the gas viscosity (Pa·s), and v_{gas} is the gas flow velocity (m/s). ΔP is obtained by calculating the difference between the pressures measured with pressure gauges installed at the tuyere and on a furnace wall of an upper part of the test furnace (in the space above the packed bed). For example, H is determined by measuring the position of the surface of the packed bed with a measuring jig having been inserted through a hole perforated in an upper portion of the test furnace, and calculating the distance in the height direction between the position of the surface of the packed bed and the position where the tuyere is located. The position of the surface of the packed bed may be measured with a laser rangefinder. ρ_{gas}

can be calculated from the type of the gas component introduced from the tuyere, the temperature inside the furnace, and the pressure inside the furnace. μ_{gas} can be calculated from the type of the gas component introduced from the tuyere, and the temperature inside the furnace. v_{gas} can be calculated from the flow rate of the gas introduced from the tuyere, the temperature inside the furnace, and the pressure inside the furnace. Here, the temperature inside the furnace is the average of temperatures measured with a plurality of thermometers installed at positions on the furnace wall corresponding to the packed bed. Similarly, the pressure inside the furnace is the average of pressures measured with a plurality of pressure gauges installed at positions on the furnace wall corresponding to the packed bed. The pressure inside the furnace may be the average of the pressure at the tuyere used to calculate ΔP and the pressure at the upper portion of the packed bed.

[0037] The gas permeability resistance index KS is calculated using the equation (6) below.
[Math. 4]

$$\mathrm{KS} = \int_{1000^{\circ}\mathrm{C}}^{\mathrm{Tmax}} \mathrm{K}\,\mathrm{dt} \quad \cdots (6)$$

[0038] In the equation (6), Tmax is the maximum temperature in the measurement of the pressure loss in the furnace and is approximately 1500 to 1650°C, although variable every time the measurement is performed.

[0039] Fig. 4 is a graph illustrating a relationship between the amount of metal iron drops and the area of boundary S_{unit} between the ferrous raw material and the coke per unit ferrous raw material. The abscissa in Fig. 4 is the area of boundary (m^2/ton of ore) between the ferrous raw material and the coke per unit ferrous raw material, and the ordinate is the dimensionless amount (-) of metal drops. The dimensionless amount of metal drops is the dimensionless amount of metal iron drops relative to 1.0 of the amount of metal iron drops when the area of boundary S_{unit} per unit ferrous raw material is 25 m^2/ton of ore. The unit (-) means dimensionless.

[0040] Fig. 5 is a graph illustrating a relationship between the gas permeability resistance index KS and the area of boundary S_{unit} between the ferrous raw material and the coke per unit ferrous raw material. The abscissa in Fig. 5 is the area of boundary (m^2/ton of ore) between the ferrous raw material and the coke per unit ferrous raw material, and the ordinate is the gas permeability resistance index KS (10^5°C/m).

[0041] As illustrated in Fig. 4, it was shown that the amount of metal iron drops increased when the area of boundary S_{unit} between the ferrous raw material and the coke per unit ferrous raw material was 25 m^2/ton of ore or more. This is probably because the metal iron produced by reduction has more opportunities to be in contact with carbon in the coke, and the metal iron is carburized and comes to have a lowered melting point.

[0042] When the area of boundary S_{unit} between the ferrous raw material and the coke per unit ferrous raw material was 25 m^2/ton of ore or more, as illustrated in Fig. 5, the gas permeability resistance index KS fell to or below the target 2000 owing to the increase in the amount of metal iron drops. The target value of the gas permeability resistance index KS, namely, 2000, is a threshold for the feasibility of continuous stable testing. The term stable testing means that the surface height of the packed bed descends uniformly over time and the test is free from troubles, such as gas channeling.

[0043] These results have shown that a test in which a high-concentration reducing gas is generated in a raceway in the furnace can be performed stably by controlling the area of boundary S_{unit} between the ferrous raw material and the coke per unit ferrous raw material to 25 m^2/ton of ore or more.

[0044] The blast furnace operation method according to the present embodiment has been developed based on the above test results. The blast furnace operation method is a method of operating a blast furnace while charging a ferrous raw material and coke from a blast furnace top, and injecting from a blast furnace tuyere a gas that generates a high-concentration reducing gas in the raceway in the furnace; and includes controlling the area of boundary S_{unit} between the ferrous raw material and the coke per unit ferrous raw material to a predetermined range.

[0045] Here, it is preferable that the area of boundary S_{unit} between the ferrous raw material and the coke per unit ferrous raw material be controlled to 25 m^2/ton of ore or more. In this manner, a sufficient amount of metal iron drops can be obtained and the blast furnace can be operated stably. If, on the other hand, the area of boundary S_{unit} between the ferrous raw material and the coke per unit ferrous raw material is less than 25 m^2/ton of ore, a sufficient amount of metal iron drops cannot be obtained and the gas permeability resistance index KS is increased.

[0046] The area of boundary S_{unit} is increased by increasing the mass W_c of the coke mixed per ferrous raw material layer in the furnace, or by decreasing the mass W_{Iron} of the ferrous raw material per ferrous raw material layer in the furnace. In blast furnace operation, normally, increasing the mass W_c of the coke mixed per ferrous raw material layer in the furnace is accompanied by decreasing the amount of the coke charged into the coke layer in order to keep the ratio of the coke to the ferrous raw material constant. As a result, the coke layer is reduced in thickness. When, on the other hand, the mass W_{Iron} of the ferrous raw material per ferrous raw material layer in the furnace is decreased, the ferrous raw material layer is reduced in thickness. Because the raw materials do not necessarily descend at a constant rate in the radial direction of the blast furnace, excessive thinning of the coke layers or the ferrous raw material layers may lead to collapse of the layered structure of the coke layers and the ferrous raw material layers. In order to ensure that the ferrous raw material and the coke that have been alternately charged in the blast furnace to form a layered structure will descend in the blast furnace while remaining layered, it is preferable that the area of boundary S_{unit} be controlled to 53.1 m^2/ton of ore or less.

[0047] The high-concentration reducing gas is preferably such that the volume of H_2 gas (including hydrogen in hydrocarbons) in the high-concentration reducing gas is in the range of 0 to 500 Nm^3/ton of molten pig iron. In this case, it is possible to prevent the decrease in in-furnace temperature and the decrease in reduction reaction rate. If, on the other hand, the volume of H_2 gas in the high-concentration reducing gas is more than 500 Nm^3/ton of molten pig iron, the in-furnace temperature is disadvantageously lowered to give rise to a decrease in reduction reaction rate. When H_2 gas alone is injected, it is preferable that the H_2 gas be heated before blowing in order to maintain the raceway temperature within an operable range.

[0048] In a blast furnace operation that generates a high-concentration reducing gas in a raceway in the furnace, as described hereinabove, the blast furnace operation method according to the present embodiment charges a ferrous raw material and coke from the furnace top while controlling the area of boundary S_{unit} between these materials per unit ferrous raw material to a predetermined range. This control promotes the carburization of metal iron that is produced and lowers the melting point of the metal iron, thus allowing the metal iron to exhibit appropriate liquid permeability through the cohesive zone and the dripping zone in the blast furnace. As a result, the gas permeability in the blast furnace can be maintained in an operable range, and the blast furnace can be operated stably.

EXAMPLES

[0049] A blast furnace operation test was performed in which a ferrous raw material and coke were alternately charged from the top of a large blast furnace and a high-concentration reducing gas was generated in a raceway in the furnace. The area of boundary S_{unit} per unit ferrous raw material between the ferrous raw material and the coke charged from the furnace top was changed while keeping constant the mass of the ferrous raw material and the mass of the coke raw material. The operation conditions and the test results are described in Table 1 below.

[Table 1]

	Items	Units	INV. EX. 1	INV. EX. 2	COMP. EX. 1
Furnace body	Furnace diameter	m	15	15	15
Conditions of charging of iron-source raw material and coke	Inclination angle θ	°	22	22	22
	Mass W_{Iron} of ferrous raw material	tons/charge	178	178	178
	Mass of coke raw material	tons/charge	28.2	28.2	28.2
	Apparent density ρ_c of coke	kg/m^3	800	800	800
	Particle size d of coke mixed	mm	25	25	25
	Mass W_c of coke mixed	tons/charge	13.5	9.5	6
	Area of boundary S_{unit}	m^2/ton of ore	34.4	25.0	16.9
Bosh gas	CO gas	vol%	62	62	62
	H_2 gas	vol%	38	38	38
	N_2 gas	vol%	0	0	0
	H_2 volume	Nm^3/ton of molten pig iron	430	430	430
Operation data	Methane ratio*1	Kg/ton of molten pig iron	155	155	155
	Unit consumption of blast volume	Nm^3/ton of molten pig iron	350	350	350
	Oxygen enrichment	% (dry)	100	100	100
Operation results	Metal iron liquid permeability	-	Good	Good	Poor
	Gas permeability	-	Good	Good	Poor
*1: The methane ratio is the amount of methane injected per ton of molten pig iron.					

[0050] In INVENTIVE EXAMPLES 1 and 2, the ferrous raw material and the coke were charged from the furnace top with control of the area of boundary S_{unit} per unit ferrous raw material to the range of the present invention. As described in Table 1, it was confirmed that these examples realized good metal iron liquid permeability and good gas permeability and made stable operation possible. In COMPARATIVE EXAMPLE 1, the ferrous raw material and the coke that were charged from the furnace top failed to satisfy the inventive range of the area of boundary S_{unit} per unit ferrous raw material. As a result, sufficient metal iron liquid permeability could not be obtained and the gas permeability was also poor.

Claims

1. A blast furnace operation method of operating a blast furnace while alternately charging a ferrous raw material and coke from a blast furnace top, and injecting from a blast furnace tuyere a gas that generates a high-concentration reducing gas in a raceway in the blast furnace, the method comprising controlling the area of boundary between the ferrous raw material and the coke per unit ferrous raw material to a predetermined range.

2. The blast furnace operation method according to claim 1, wherein the area of boundary per unit ferrous raw material is the total of the area of boundary between a ferrous raw material layer and a coke layer per unit ferrous raw material plus the area of boundary between the ferrous raw material and coke particles mixed in the ferrous raw material layer.

3. The blast furnace operation method according to claim 2, wherein the area of boundary per unit ferrous raw material is controlled to 25 m^2/ton of ore or more.

4. The blast furnace operation method according to claim 1, wherein the high-concentration reducing gas, when expressed by bosh gas composition, is composed of H_2 gas, N_2 gas, and CO gas; has a composition of H_2 gas, N_2 gas, and CO gas within a region enclosed by four points in a H_2 gas-N_2 gas-CO gas ternary diagram wherein the four points are a point at H_2 gas: 0 vol%, N_2 gas: 0 vol%, and CO gas: 100 vol%, a point at H_2 gas: 100 vol%, N_2 gas: 0 vol%, and CO gas: 0 vol%, a point at H_2 gas: 29 vol%, N_2 gas: 71 vol%, and CO gas: 0 vol%, and a point at H_2 gas: 0 vol%, N_2 gas: 37 vol%, and CO gas: 63 vol%; and includes H_2 gas in the range of 0 to 100 vol%, N_2 gas in the range of 0 to 71 vol%, and CO gas in the range of 0 to 100 vol%.

5. The blast furnace operation method according to claim 2, wherein the high-concentration reducing gas, when expressed by bosh gas composition, is composed of H_2 gas, N_2 gas, and CO gas; has a composition of H_2 gas, N_2 gas, and CO gas within a region enclosed by four points in a H_2 gas-N_2 gas-CO gas ternary diagram wherein the four points are a point at H_2 gas: 0 vol%, N_2 gas: 0 vol%, and CO gas: 100 vol%, a point at H_2 gas: 100 vol%, N_2 gas: 0 vol%, and CO gas: 0 vol%, a point at H_2 gas: 29 vol%, N_2 gas: 71 vol%, and CO gas: 0 vol%, and a point at H_2 gas: 0 vol%, N_2 gas: 37 vol%, and CO gas: 63 vol%; and includes H_2 gas in the range of 0 to 100 vol%, N_2 gas in the range of 0 to 71 vol%, and CO gas in the range of 0 to 100 vol%.

6. The blast furnace operation method according to claim 3, wherein the high-concentration reducing gas, when expressed by bosh gas composition, is composed of H_2 gas, N_2 gas, and CO gas; has a composition of H_2 gas, N_2 gas, and CO gas within a region enclosed by four points in a H_2 gas-N_2 gas-CO gas ternary diagram wherein the four points are a point at H_2 gas: 0 vol%, N_2 gas: 0 vol%, and CO gas: 100 vol%, a point at H_2 gas: 100 vol%, N_2 gas: 0 vol%, and CO gas: 0 vol%, a point at H_2 gas: 29 vol%, N_2 gas: 71 vol%, and CO gas: 0 vol%, and a point at H_2 gas: 0 vol%, N_2 gas: 37 vol%, and CO gas: 63 vol%; and includes H_2 gas in the range of 0 to 100 vol%, N_2 gas in the range of 0 to 71 vol%, and CO gas in the range of 0 to 100 vol%.

7. The blast furnace operation method according to any one of claims 1 to 6, wherein the volume of H_2 in the high-concentration reducing gas is in the range of 0 to 500 Nm^3/ton of molten pig iron.

FIG. 1

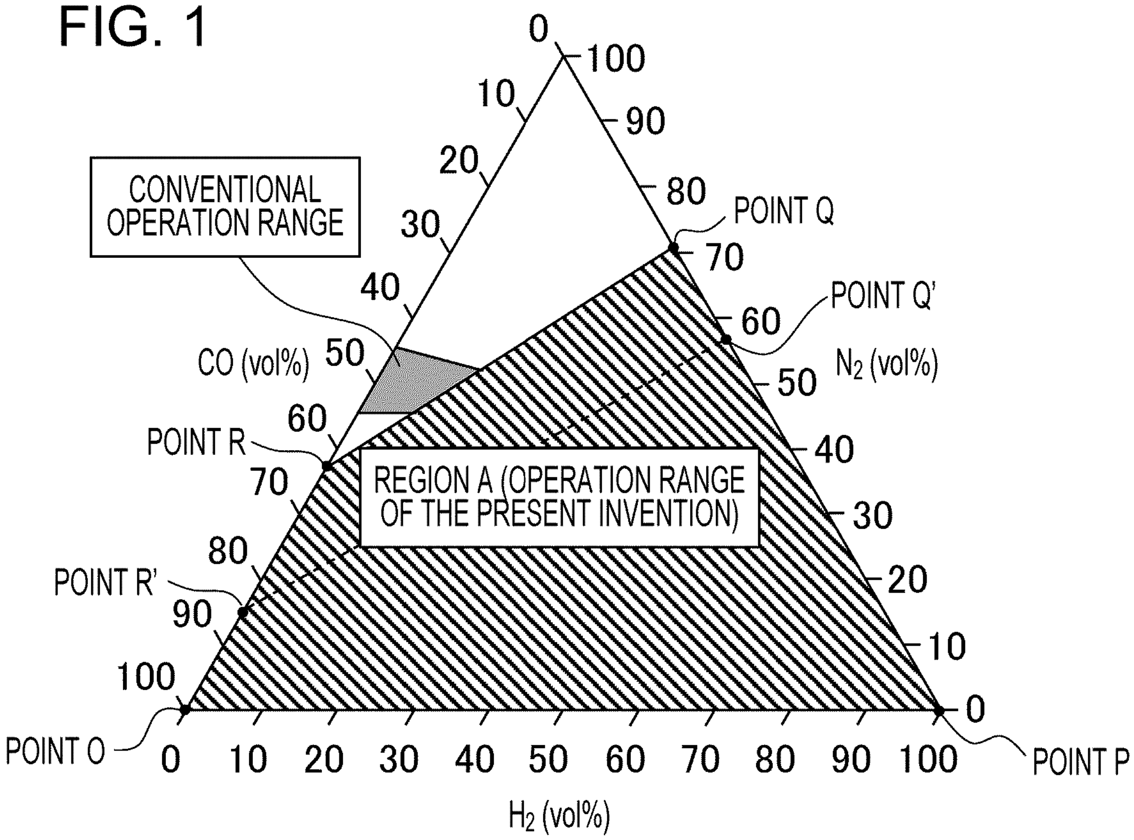

CONVENTIONAL OPERATION RANGE
REGION A (OPERATION RANGE OF THE PRESENT INVENTION)
POINT Q
POINT Q'
POINT R
POINT R'
POINT O
POINT P
CO (vol%)
N_2 (vol%)
H_2 (vol%)
0
10
20
30
40
50
60
70
80
90
100

FIG. 2

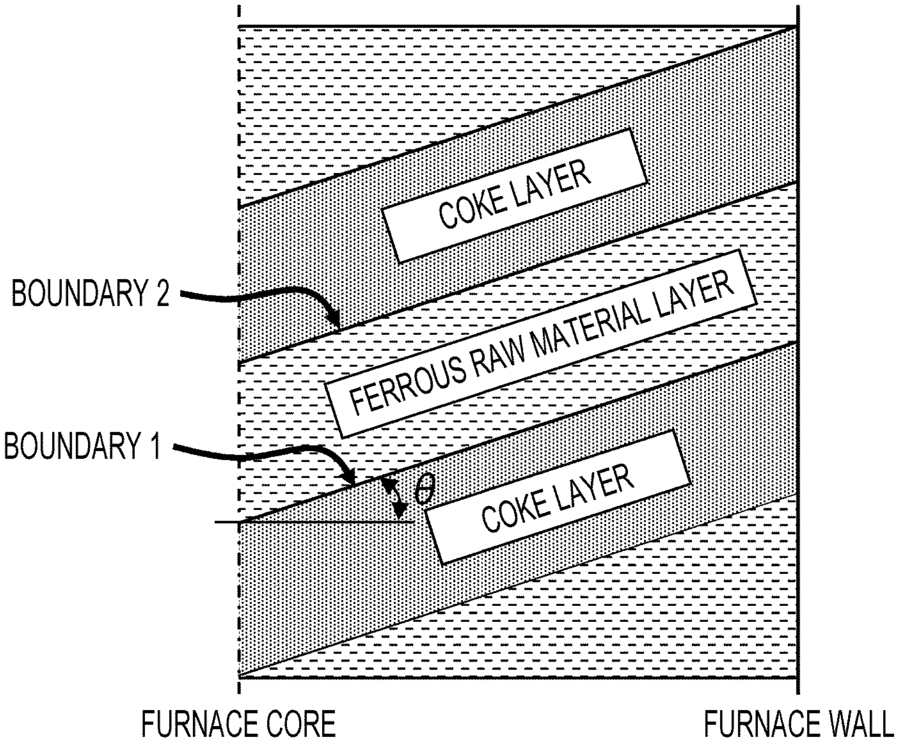
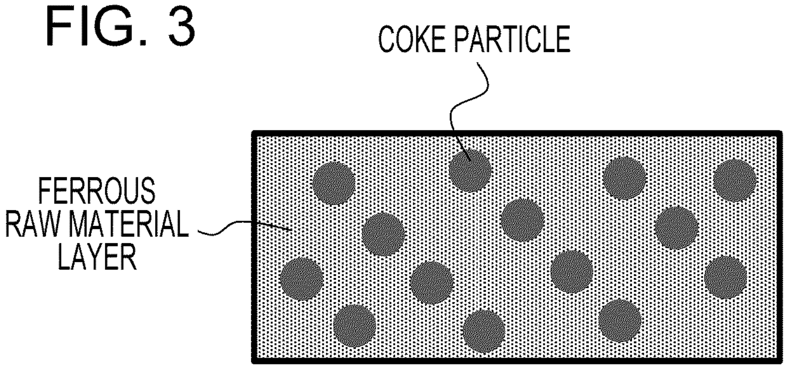
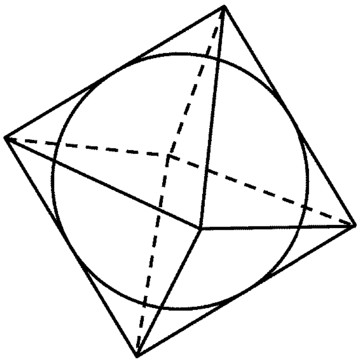

COKE LAYER
FERROUS RAW MATERIAL LAYER
COKE LAYER
BOUNDARY 2
BOUNDARY 1
θ
FURNACE CORE
FURNACE WALL

FIG. 3


COKE PARTICLE
FERROUS RAW MATERIAL LAYER

(A)



(B)

FIG. 4

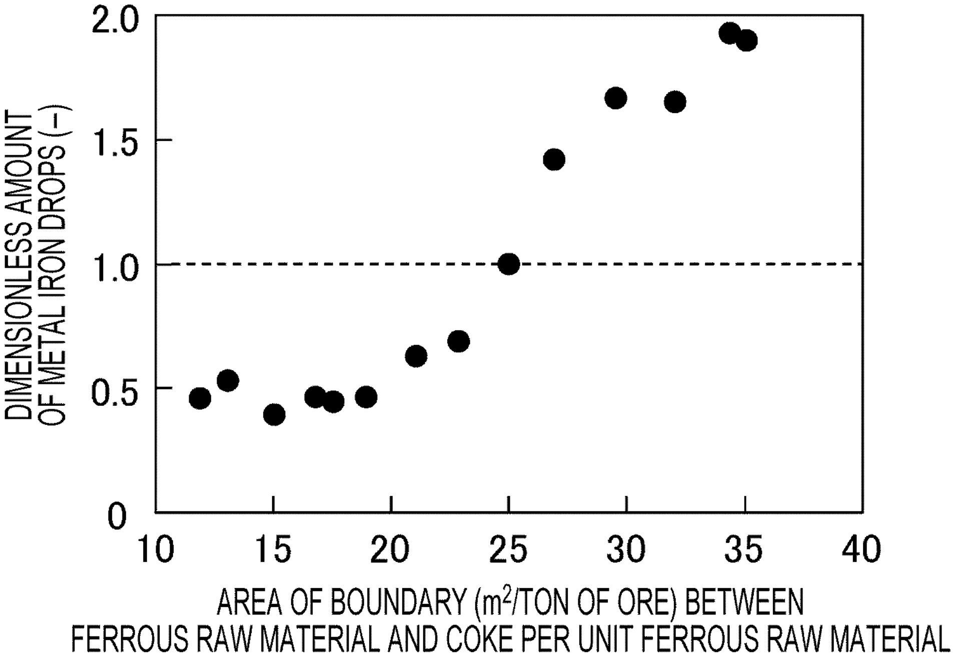
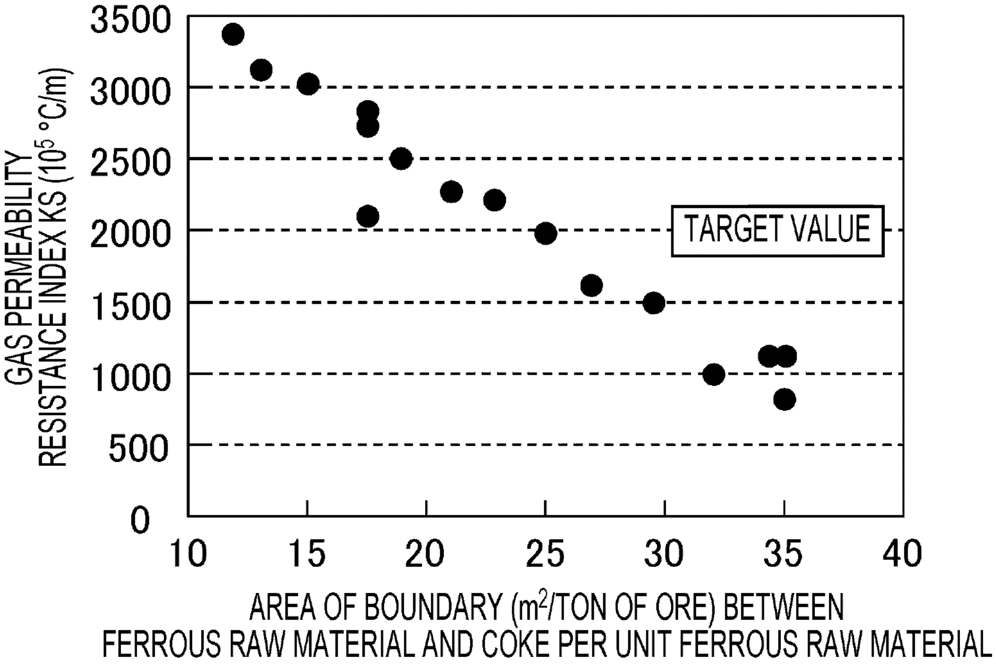

2.0
1.5
1.0
0.5
0
10
15
20
25
30
35
40
DIMENSIONLESS AMOUNT OF METAL IRON DROPS (−)
AREA OF BOUNDARY (m²/TON OF ORE) BETWEEN FERROUS RAW MATERIAL AND COKE PER UNIT FERROUS RAW MATERIAL

FIG. 5


GAS PERMEABILITY
RESISTANCE INDEX KS (10^5 °C/m)
3500
3000
2500
2000
1500
1000
500
0
TARGET VALUE
10
15
20
25
30
35
40
AREA OF BOUNDARY (m^2/TON OF ORE) BETWEEN
FERROUS RAW MATERIAL AND COKE PER UNIT FERROUS RAW MATERIAL

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2022/046306

A. CLASSIFICATION OF SUBJECT MATTER

C21B 5/00(2006.01)i
FI: C21B5/00 311; C21B5/00 302; C21B5/00 321

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)

C21B5/00

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

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 63-161104 A (KAWASAKI STEEL CORP.) 04 July 1988 (1988-07-04) claims, page 1, left column, line 13 to page 2, upper right column, line 19, page 5, upper left column, lines 1-17	1-3
Y	claims, page 1, left column, line 13 to page 2, upper right column, line 19, page 5, upper left column, lines 1-17	4-7
Y	JP 60-228610 A (NIPPON KOKAN KK) 13 November 1985 (1985-11-13) claims, page 1, left column, line 10 to page 2, upper left column, line 17, examples	1-7
Y	大野陽太郎･松浦正博, 酸素高炉プロセスにおける炉内装入物の昇温, 反応特性, 鉄と鋼, 1990, vol. 76, no. 8, pages 60-67, particularly, table 1, (OHNO, Yataro, MATSUURA, Masahiro. Heating-up and Reaction Characteristics of Burdens in Oxygen Blast Furnace Process. Tetsu-to-Hagane.) particularly, table 1	1-7

☐ 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 **07 February 2023**	Date of mailing of the international search report **21 February 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.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2022/046306

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 63-161104 A	04 July 1988	(Family: none)	
JP 60-228610 A	13 November 1985	(Family: none)	

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

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 2000256712 A **[0010]**
- JP 2002129211 A **[0010]**