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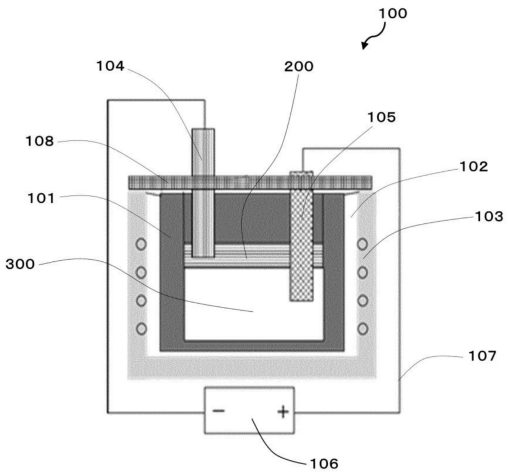
(54) METHOD FOR DEPHOSPHORIZING MOLTEN IRON

(57) To provide a method for dephosphorizing molten iron that can effectively improve the phosphorus distribution and thus promote a dephosphorization reaction of molten iron by providing electric energy using an electrochemical method. Specifically, provided is a method for dephosphorizing molten iron, applying a current between molten slag and molten iron via two electrodes, with one in contact with the molten iron serving as an anode and the other in contact with only the molten slag serving as a cathode, characterized in that Relational Expression (1) below is satisfied among the density I of the applied current, the molten steel temperature T of the molten iron, the phosphorus distribution Lp in the molten slag, and the required phosphorus distribution Lp' for the molten slag:

$$[\text{Math. 1}]\ I \geq \alpha \times \ln(Lp'/Lp) \times T \quad ...(1),$$

where in Relational Expression (1), I represents the density (A/m^2) of the applied current, α represents the constant, Lp represents the phosphorus distribution (-) in the molten slag, Lp' represents the required phosphorus distribution (-) for the molten slag, and T represents the molten steel temperature (K) of the molten iron.

[Fig. 1]



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Description

Technical Field

[0001] The present invention relates to a method for dephosphorizing molten iron. In particular, the present invention relates to a method for dephosphorizing molten iron that can promote dephosphorization reactions.

Background Art

[0002] Phosphorus contained in molten steel tends to be segregated at grain boundaries in a material formed from the molten steel, resulting in reduced strength and toughness of steel formed from the molten steel. Accordingly, when producing steel from molten steel, the phosphorus content in the molten steel is typically controlled to remain low.

[0003] In recent years, there has been growing demand for the production of high-grade steel, and further reduction of the phosphorus content in molten steel has been desired. However, the burden on dephosphorizing molten iron has become increasingly severe due to factors such as degraded quality of iron ore, which serves as a raw material for molten steel. From such a technical perspective, it is essential to develop a technology for reducing the phosphorus concentration in molten steel after the molten steel has been processed.

[0004] In a conventional technology for dephosphorizing molten steel, since phosphorus oxide contained in the molten steel is acidic, lime-based flux such as CaO is added to the molten steel to increase the basicity of molten slag formed during the production of the molten steel. Adding the lime-based flux, such as CaO, into the molten steel enhances the dephosphorization capability of molten slag, thereby reducing the equilibrium phosphorus concentration in the molten steel.

[0005] However, molten slag with higher basicity has a higher melting temperature. Therefore, if the molten steel temperature drops during the preliminary treatment of molten pig iron, the viscosity of the molten slag increases. This may result in insufficient slag formation from CaO, which is contained in the lime-based flux introduced into the molten steel, leading to a reduced dephosphorization efficiency. To increase such low dephosphorization efficiency in order to compensate for the efficiency of dephosphorization reactions, it is necessary to use an excess refining material for the molten steel. However, using an excess refining material for the molten steel increases cost for refining the molten steel. Further, if dephosphorization is performed to reduce the concentration of phosphorus in the molten steel to an extremely low level, the amount of the molten slag becomes excessive. This may lead to problems such as insufficient capacity at a molten steel refining facility or a slag removal facility.

[0006] To address this challenge, in dephosphorization of molten steel aiming to achieve an extremely low phosphorus concentration, a method has been adopted in which a halide, such as fluorite (CaF_2), is added to promote slag formation from CaO contained in a lime-based flux and thereby reduce the amount of flux to be charged. This method enables both high dephosphorization capability and a reduced amount of molten slag, thereby maintaining a high dephosphorization rate even in a region of extremely low phosphorus concentration.

[0007] However, adding halide, such as fluorite (CaF_2), into the molten steel results in an increased content of fluorine (F) in the resulting molten slag. In recent years, there have been growing social concerns about environmental issues, and the use that evokes concerns about the elution of fluorine (F) has been regulated. From this perspective, the use of halide such as fluorite (CaF_2) for molten steel has become difficult. Therefore, there is a need for a technology that can efficiently dephosphorize molten steel without increasing the basicity of slag.

[0008] In view of the foregoing circumstances, research has been conducted on a technology for efficiently dephosphorizing molten steel without increasing the basicity of molten slag, with a focus on electric energy. For example, Non Patent Literature 1 discloses a method for promoting dephosphorization reactions where a reaction that occurs at the interface between slag and molten iron (hereinafter referred to as a "slag-metal reaction") is arranged based on the concept of electrochemistry. Specifically, Non Patent Literature 1 presents the concept of a reaction promoted by electric energy, citing an example where polarizing the potential of molten iron toward the noble side causes iron to be removed through oxidation into the slag. Conversely, polarizing it toward the less noble side reduces iron ions in the slag, returning them to the molten iron. Various research related to slag-metal reactions has been reported based on Non Patent Literature 1.

[0009] Patent Literature 1 discloses a method of applying a current, using one electrode in contact with molten slag and another in contact with an iron bath, thereby reducing the content of metallic iron droplets in molten slag and variation in the metallic iron content in the slag per charge.

[0010] Patent Literature 2 discloses a method in which impurities such as phosphorus and sulfur in steelmaking slag are transferred into molten iron scraps settled on the furnace bottom, allowing the impurities to be absorbed and thereby regenerating steelmaking slag. This method of regenerating steelmaking slag described in Patent Literature 2 involves applying a current, with one electrode on the slag side as an anode and another on the molten iron scrap side as a cathode, thereby reducing phosphorus and sulfur in the slag, and transferring them into the molten iron scraps.

Citation List

Patent Literature

[0011]

Patent Literature 1: Japanese Patent No. 7158570
Patent Literature 2: Japanese Patent Laid-Open No. 11-302719

Non Patent Literature

[0012] Non Patent Literature 1: TOKUDA Masanori, "Coupling Phenomenon During Slag-Metal Reaction," Bulletin of the Japan Institute of Metals, Vol. 15, No. 6 (1976), accepted on February 17, 1976

Summary of Invention

Technical Problem

[0013] However, the above-described conventional technologies have the following problems to be solved. That is, Non Patent Literature 1 discloses a method for promoting dephosphorization reactions by organizing slag-metal reactions from electrochemical perspective. However, the method for promoting dephosphorization reactions of molten iron described in Non Patent Literature 1 involves changing a mixed potential of a dephosphorization reaction system for molten iron and an equilibrium potential of a phosphorus reaction using additives and the like, without supplying electric energy from the outside to promote dephosphorization reactions. Meanwhile, the technology disclosed in Patent Literature 1 involves applying a current between slag and metal. The purpose of applying a current between slag and metal in the method for processing molten slag described in Patent Literature 1 is to reduce the content of metallic iron droplets in the slag and variation thereof. That is, applying a current between slag and metal in the method for processing molten slag described in Patent Literature 1 has the effect of promoting the coalescence and coarsening of metallic iron droplets. Therefore, this method neither considers the effects on electrochemical reactions nor promotes dephosphorization reactions of molten iron.

[0014] The technology disclosed in Patent Literature 2 uses electric energy for electric heating to melt molten slag and iron scrap; however, it does not facilitate electrochemical reactions. Moreover, the technology disclosed in Patent Literature 2 is designed to promote so-called rephosphorization by removing phosphorus from molten slag and transferring the removed phosphorus to molten iron, and therefore does not promote dephosphorization reactions of molten iron.

[0015] The present invention has been made in view of such circumstances, and it is an object of the present invention to provide a method for dephosphorizing molten iron that can effectively improve the phosphorus distribution and thus promote a dephosphorization reaction of molten iron by supplying electric energy using an electrochemical method.

Solution to Problem

[0016] As a result of various experiments conducted to address the aforementioned issues, the present inventors have made the following findings. That is, in a method for dephosphorizing molten iron by applying a current between molten slag and molten iron, controlling the applied current based on the relationship among the phosphorus distribution in the molten slag, the required phosphorus distribution in the molten slag, and the molten steel temperature of the molten iron can effectively promote phosphorus distribution and thereby facilitate a dephosphorization reaction of the molten iron. The present invention has been made based on the findings, and the summary of the present invention is as follows.

[0017] That is, a method for dephosphorizing molten iron according to the present invention, which advantageously solves the problems, includes applying a current between molten slag and molten iron via two electrodes, with one electrode in contact with the molten iron serving as an anode and the other in contact with only the molten slag serving as a cathode, characterized in that a density I of the applied current satisfies Relational Expression (1) below, in relation to a molten steel temperature T of the molten iron, a phosphorus distribution LP in the molten slag, and a required phosphorus distribution LP' in the molten slag:

[Math. 1]

$$I \geq \alpha \times \ln(Lp'/Lp) \times T \quad ...(1),$$

where, in Relational Expression (1), I represents the density (A/m^2) of the applied current, α represents a constant, LP represents the phosphorus distribution (-) in the molten slag, LP' represents the required phosphorus distribution (-) in the molten slag, and T represents the molten steel temperature T (K) of the molten iron.

[0018] It should be noted that the method for dephosphorizing molten iron according to the present invention may include the following features that are considered to be more preferable solution means.

(a) A concentration [C] of carbon contained in the molten iron is 4.0 mass% or less, and the density I (A/m^2) of the applied current satisfies Relational Expression (2) below:
[Math. 2]

$$I \geq 5.264 \times 10^{-2} \ln(Lp'/Lp) \times T \quad ...(2),$$

where I represents the density (A/m^2) of the applied current, Lp represents the phosphorus distribution (-) in the molten slag, Lp' represents the required phosphorus distribution (-) in the molten slag, and T represents the molten steel temperature (K) of the molten iron.
(b) Arc discharge is not generated by applying a current between the molten slag and the molten iron.
(c) A value of the current is 5000 (A) or less.
(d) A liquid phase ratio of the molten slag is 60 vol.% or greater.

Advantageous Effects of Invention

[0019] According to the present invention, it is possible to effectively improve the phosphorus distribution and promote a dephosphorization reaction of molten iron without modifying slag by supplying electric energy to the molten iron through an electrochemical method.

Brief Description of Drawings

[0020]

[Fig. 1] is a schematic view illustrating an overview of a molten iron dephosphorization apparatus used to perform a method for dephosphorizing molten iron according to the present embodiment.
[Fig. 2] is a graph illustrating the relationship between the dephosphorization processing time (min) and the phosphorus concentration (mass%) of molten iron when the method for dephosphorizing molten iron according to the present embodiment is performed.
[Fig. 3] is a graph illustrating the relationship between the density of an applied current and the distribution of phosphorus contained in molten iron when a current is applied to electrodes using the molten iron dephosphorization apparatus.

Description of Embodiments

[First embodiment]

[0021] A method for dephosphorizing molten iron according to a first embodiment will be described. The method for dephosphorizing molten iron according to the present embodiment includes applying a current between molten slag and molten iron via two electrodes, with one electrode in contact with the molten iron serving as an anode and the other in contact with only the molten slag serving as a cathode. A molten iron dephosphorization apparatus used to perform the method for dephosphorizing molten iron according to the present embodiment will also be described.

<Overview of molten iron dephosphorization apparatus>

[0022] Fig. 1 is a schematic view illustrating an overview of a molten iron dephosphorization apparatus used to perform the method for dephosphorizing molten iron according to the present embodiment. As illustrated in Fig. 1, a molten iron dephosphorization apparatus 100 includes an MgO crucible 101, a refractory ramming mix 102, and an induction melting furnace 103. Molten iron formed by melting scraps, molten pig iron, and the like is charged into the MgO crucible 101. The MgO crucible 101 is preferably formed of a material that has low solubility with respect to molten iron and is thermodynamically stable.

[0023] Examples of crucibles that can be used other than the MgO crucible 101 include a CaO crucible and an Al_2O_3

crucible. The shape of the MgO crucible 101 is not limited to a particular shape, but may be a cylindrical shape. If the shape of the MgO crucible 101 is a cylindrical shape, the cross-sectional area thereof may be 0.005 to 0.030 m^2, for example, 0.018 m^2.

[0024] The refractory ramming mix 102 is a refractory. The refractory ramming mix 102 covers the sidewall and the bottom face of the MgO crucible 101 and is attached to the inner wall of the induction melting furnace 103. The thickness of the refractory ramming mix 102 is preferably 100 to 150 mm from the perspective of ensuring heat resistance and durability. The induction melting furnace 103 is a low-frequency induction furnace in the form of a crucible. The induction melting furnace 103 can hold molten iron while maintaining a high temperature. The sidewall of the induction melting furnace 103 may be provided with an induction heater.

[0025] Further, the molten iron dephosphorization apparatus 100 includes a cathode 104 and an anode 105, which are configured to apply current between molten slag 200 and molten iron 300 charged into the MgO crucible 101. The cathode 104 is in contact only with the molten slag 200 and not in contact with the molten iron 300, which is positioned below the lower surface of the molten slag 200. The cathode 104 is preferably formed from a heat-resistant material, as the temperature of the molten slag 200 charged into the MgO crucible 101 is extremely high. The material forming the cathode 104 is preferably graphite or artificial graphite. The cathode 104 may be shaped as a bar or a plate.

[0026] The anode 105 is in contact with the molten iron 300. The anode 105 is in contact with both the molten slag 200 and the molten iron 300. The anode 105 is preferably formed from a heat-resistant material, as the molten steel temperature of both the molten slag 200 and the molten iron 300 charged into the MgO crucible 101 is extremely high. The material forming the anode 105 may be carbon or a composite material such as C-MgO. The anode 105 may take the form of, for example, a core metal portion of a gas-stirring lance immersed in the molten iron (molten metal), which stirs the molten iron (molten metal) by blowing an inert gas such as argon or nitrogen gas. Alternatively, it may be a graphite-containing refractory brick that is installed to extend just below the bath surface level of the molten iron (molten metal).

[0027] The cathode 104 attached to the induction melting furnace 103, and a negative electrode of a DC power supply 106 provided outside the induction melting furnace 103 are connected via a cable 107. The anode 105 attached to the induction melting furnace 103 and a positive electrode of the DC power supply 106 provided outside the induction melting furnace 103 are connected via a cable 107. In this manner, two electrodes including the cathode 104 and the anode 105 are connected to the DC power supply 106 provided outside the induction melting furnace 103, thereby forming an electric circuit.

[0028] In the molten iron dephosphorization apparatus 100, the upper surfaces of the MgO crucible 101, the refractory ramming mix 102, and the induction melting furnace 103 are covered with a heat-insulating board 108. The heat-insulating board 108 maintains the temperature of the molten iron 300 charged into the MgO crucible 101 by covering the upper surfaces of the MgO crucible 101, refractory ramming mix 102, and induction melting furnace 103. The material of the heat-insulating board 108 is not limited to a particular material, as long as it possesses a heat insulation property.

<Dephosphorization of molten iron via application of current>

[0029] The method for dephosphorizing molten iron according to the present embodiment involves applying a current between molten slag and molten iron via two electrodes, with one electrode in contact with molten iron serving as an anode and the other in contact with only molten slag serving as a cathode.

[0030] Hereinafter, dephosphorization of molten iron by applying a current in the method for dephosphorizing molten iron according to the present embodiment will be described.

[0031] Industrial pure iron is charged into the MgO crucible 101. The refractory ramming mix 102 is embedded in the outer wall of the MgO crucible 101, and the industrial pure iron is heated and melted using the induction melting furnace 103, thereby producing the molten iron 300. The concentration of phosphorus contained in the molten iron 300 is adjusted to fall within a predetermined range. Herein, the concentration of phosphorus contained in the molten iron 300 may be 0.01 to 0.20 mass%, preferably 0.05 to 0.15 mass%, and further preferably 0.08 mass%. The total amount of the molten iron 300 to be produced by melting industrial pure iron may be set to 5 to 30 kg, preferably 10 to 20 kg, and further preferably 15 kg.

[0032] Further, flux is charged onto the upper surface of the molten iron 300 in the molten iron dephosphorization apparatus 100 to form the molten slag 200 on the upper surface of the molten iron 300. The amount of the flux to be charged may be appropriately determined based on the internal volume of the MgO crucible 101, the total amount of the molten iron 300, and the like. The proportion of the amount of the flux to be charged may be, for example, 10 to 30 kg/molten iron-t, preferably 15 to 25 kg/molten iron-t, and further preferably 20 kg/molten iron-t.

[0033] The component composition of the flux is not limited, provided that it includes a component capable of forming the molten slag 200. For example, the component composition of the flux may include CaO, SiO_2, FeO, and MgO. If the component composition of the flux includes CaO, SiO_2, FeO, and MgO, their contents may be, in mass%, 22.5 (%CaO), 28.0 (%SiO_2), 42.5 (%FeO), and 7.0 (%MgO).

[0034] After the flux is charged onto the upper surface of the molten iron 300, the molten steel temperature of the molten iron 300 present in the MgO crucible 101 is maintained within the range of 1300 to 1700°C, preferably 1585 to 1615°C. By

charging the flux onto the molten iron 300 and maintaining its temperature, the molten slag 200 and the molten iron 300 are formed in the molten iron dephosphorization apparatus 100. The molten slag 200 is formed on the surface of the molten iron 300. An interface between the molten slag 200 (slag) and the molten iron 300 (metal) is formed between the molten slag 200 and the molten iron 300.

[0035] The thus-formed molten slag 200 has a molten slag composition that allows the cathode 104 and the anode 105, which are used to apply a current between the molten slag 200 and the molten iron, to be inserted into the molten slag 200.

[0036] The cathode 104 is immersed in the molten slag 200 formed in the molten iron dephosphorization apparatus 100. The cathode 104 is immersed in only the molten slag 200. Meanwhile, the anode 105 is immersed in both the molten slag 200 and the molten iron 300, which are formed in the molten iron dephosphorization apparatus 100. That is, the anode 105 may be immersed in both the molten slag 200 and the molten iron 300 formed with a C-MgO brick, which is a carbon-containing refractory. In this manner, a DC current is applied to the molten slag 200 and the molten iron 300 by supplying the DC power supply 106 between the two electrodes including the cathode 104 and the anode 105 provided in the molten iron dephosphorization apparatus 100.

[0037] The applied current density between the two electrodes is preferably determined by considering factors such as the dephosphorization processing time, the required phosphorus distribution based on the target phosphorus concentration, and the electricity cost. Specifically, it is possible to reduce the phosphorus concentration, which could be achieved by setting the density of the current to be applied between the two electrodes to increase the density of the current to be applied between the electrodes, thereby increasing the dephosphorization rate.

[0038] Therefore, applying a large current between the two electrodes can reduce the processing time required for the process of dephosphorizing molten iron and yield molten iron (molten metal) with a phosphorus concentration at or below the target level. However, the electricity cost associated with this approach is substantial. From this technical perspective, it is possible to apply a current between the two electrodes by setting the current density to satisfy Relational Expression (1) below.

[Math. 3]

$$I \geq \alpha \times \ln(Lp'/Lp) \times T \quad ...(1)$$

[0039] In Relational Expression (1), I represents the density (A/m^2) of the applied current, α represents the constant, LP represents the phosphorus distribution (-) in the molten slag, LP' represents the required phosphorus distribution (-) in the molten slag, and T represents the molten steel temperature (K) of the molten iron.

[0040] In the method for dephosphorizing molten iron according to the present embodiment, the value of the applied current density I calculated using Relational Expression (1) corresponds to the current density that can obtain the minimum effect of dephosphorization of molten iron. Two main effects are obtained when applying a current with a density equal to or greater than the value I, calculated by Relational Expression (1), between the molten slag 200 and the molten iron 300.

[0041] The first effect is that, as can be seen from Relational Expression (5) described below, the productivity of molten steel can be improved by increasing the dephosphorization reaction rate of molten iron.

[0042] The second effect is that the electricity cost for dephosphorizing molten iron may increase. That is, if the applied current density used to perform the dephosphorization of the molten iron is increased more than necessary, both the productivity and the production cost rise. Therefore, the upper limit of the density of the applied current used to perform the dephosphorization of the molten iron is desirably determined by considering parameters required for the process, such as allowable operation time, cost, and allowable current of the power supply.

[0043] From such technical perspectives, the fact that the applied current density I can be calculated using Relational Expression (1) is of significant importance, as it enables both to ensure the effect of dephosphorization of molten iron and provide suitable conditions of the method for dephosphorizing molten iron in consideration of allowable operation time, cost, and allowable current of the power supply for dephosphorization of the molten iron.

[0044] Specifically, in the method for dephosphorizing molten iron according to the present embodiment, the value of the applied current density I that can be set using Relational Expression (1) is within the range of 150 to 600 (A/m^2), and preferably within the range of 200 to 500 (A/m^2). The value of the applied current density I is preferably 150 (A/m^2) or greater, as it allows for the reduction in the phosphorus concentration to be reached in the molten iron 300 and an increase in the dephosphorization rate. The value of the applied current density I is also preferably 600 (A/m^2) or less, as it allows for the reduction in the electricity cost in the dephosphorization of the molten iron 300.

[0045] In the method for dephosphorizing molten iron according to the present embodiment, the concentration of phosphorus contained in the molten iron 300 can be measured after a predetermined period has elapsed from the start of the current application between the two electrodes.

[0046] Fig. 2 is a graph illustrating temporal changes in the concentration of phosphorus in molten iron when dephosphorization of molten iron is performed by applying a current between the two electrodes using the molten iron dephosphorization apparatus. That is, Fig. 2 illustrates the relationship between the dephosphorization processing time

(min) and the phosphorus concentration (mass%) of the molten iron. As shown in Fig. 2, it is observed that a higher applied current results in a faster dephosphorization rate and a lower resulting phosphorus concentration.

[0047] Fig. 3 is a graph illustrating the relationship between the applied current density and the distribution of phosphorus in molten slag when dephosphorizing molten iron is performed by applying a current to electrodes using a molten iron dephosphorization apparatus. Fig. 3 demonstrates that the logarithm of the phosphorus distribution Lp in the molten slag 200 tends to increase linearly with respect to the applied current density I between two electrodes. This tendency remains consistent even when the component composition of the molten slag 200 is varied. Furthermore, this tendency remains consistent even when the molten iron 300 is subjected to dephosphorization together with stirring using a bubbling lance. In addition, the inventors have confirmed that even when varying the molten steel temperature T in the method for dephosphorizing the molten iron 300, the logarithm of the phosphorus distribution in the molten slag 200 increases linearly with respect to the applied current density I.

[0048] The principle by which the method for dephosphorizing molten iron according to the present embodiment promotes the dephosphorization reaction of molten iron is considered as follows. That is, the current application to the molten iron 300 and the molten slag 200 causes the molten iron 300 side and the molten slag 200 side to become polarized to a higher potential and lower potential, respectively, via both electrodes. The change in the potential at this time is referred to as overpotential. Herein, an equilibrium reaction formula of a dephosphorization reaction of phosphorus contained in the molten iron 300 and the equilibrium constant K of the dephosphorization reaction of phosphorus are respectively represented as follows, based on the change in Gibbs energy corresponding to the overpotential.

[0049]

[Chemical Formula 1]

$$P \rightleftharpoons P^{5+} + 5e^{-} \quad ...(3)$$

[Math. 4]

$$K = \frac{[P^{5+}]}{[P]} \quad ...(4)$$

[0050] In the molten iron dephosphorization apparatus 100, applying a current to both electrodes promotes the dephosphorization reaction of phosphorus contained in the molten iron 300, thereby converting phosphorus (P) in the molten iron 300 into phosphorus ions (P^{5+}) and increasing the concentration [P^{5+}] of phosphorus ions. This increases the equilibrium constant K of the dephosphorization reaction of phosphorus contained in the molten iron 300, presumably resulting in a reduced concentration [P] of phosphorus (P) in the molten iron 300. Assuming that the dephosphorization reaction of phosphorus in the molten iron 300 is first-order, and that the reaction rate v of the dephosphorization reaction is expressed by a first-order function of the phosphorus concentration [P], Relational Expression (5) below is obtained. It should be noted that in Relational Expression (5), t represents the dephosphorization processing time t(s) for phosphorus in the molten iron, k represents the apparent reaction rate constant of the dephosphorization reaction of phosphorus contained in the molten iron, and $[P]_e$ represents the equilibrium phosphorus concentration when the dephosphorization reaction of phosphorus contained in the molten iron has reached solution equilibrium.

[Math. 5]

$$V = -d[P]/dt$$

$$= k([P] - [P]_e) \quad ...(5)$$

[0051] Relational Expression (5) indicates that a decrease in the equilibrium phosphorus concentration $[P]_e$, when the dephosphorization reaction of phosphorus in the molten iron 300 has reached the solution equilibrium, results in an increase in the reaction rate v of the dephosphorization reaction of phosphorus in the molten iron 300. In this case, provided that T (K) represents the molten steel temperature when the dephosphorization reaction of phosphorus in the molten iron 300 reaches solution equilibrium; Lp represents the distribution of phosphorus in the molten slag 200 when no current is applied to the molten iron 300 and the molten slag 200; and Lp' represents the distribution of phosphorus contained in the molten slag 200 after a current is applied to the molten iron 300 and the molten slag 200, the applied current density I

required to achieve desired phosphorus distribution Lp' is given by Relational Expression (1) below.
[Math. 6]

$$I \geq \alpha \times \ln(Lp'/Lp) \times T \quad ...(1)$$

[0052] In Relational Expression (1), I represents the applied current density (A/m^2), α represents a constant, Lp represents the phosphorus distribution (-) in the molten slag, Lp' represents the required phosphorus distribution (-) in the molten slag, and T represents the molten steel temperature (K) of molten iron.

[0053] That is, for Relational Expression (1), the concentration C_{slag} of phosphorus in the molten slag and the concentration C_{iron} of phosphorus in the molten iron at the molten steel temperature T (K) after a predetermined time has elapsed, are calculated to determine the phosphorus distribution Lp (-) in the molten slag 200. Thereafter, the required phosphorus distribution LP' (-) in the molten slag 200 is determined when a current is applied between two electrodes using the molten iron dephosphorization apparatus 100, thereby promoting the dephosphorization reaction of phosphorus in the molten iron 300 and reaching solution equilibrium.

[0054] After the phosphorus distribution Lp (-) in the molten slag 200 at the molten steel temperature T (K) is calculated and the required phosphorus distribution LP' (-) in the molten slag 200 is determined, the applied current density I (A/m^2) corresponding to the required phosphorus distribution LP' (-) in the molten slag 200 can be calculated using Relational Expression (1).

[0055] Herein, the constant α in Relational Expression (1) is calculated as follows. First, the relationship between the applied current density I (A/m^2) and an overpotential η generated between electrodes, formed by the cathode 104 and the anode 105 when a current is applied to the molten iron 300 and the molten slag 200, is determined. The applied current density I (A/m^2) and the overpotential η have a proportional relationship and can be represented by Relational Expression (6) below. Therefore, the slope α can be calculated from a graph illustrating the relationship between the applied current density I (A/m^2) and the overpotential η.
[Math. 7]

$$\eta = \alpha \times I \quad ...(6)$$

[0056] Meanwhile, when a current is applied to the molten iron 300 and the molten slag 200, a change $\Delta G_{initial}$ in Gibbs energy upon application of the current, and a change $\Delta G_{equilibrium}$ in Gibbs energy when phosphorus in the molten iron reaches solution equilibrium after the current application are represented by Relational Expressions (7) and (8) below, respectively.
[Math. 8]

$$\Delta G_{initial} = \Delta G_{0initial} + RT \ln \left(Lp \times \frac{a_{slag}}{a_{iron}}\right) \quad ...(7)$$

[0057] In Relational Expression (7), R represents a gas constant, T represents the molten steel temperature (K), Lp represents the phosphorus distribution (-) in the molten slag, a_{slag} represents the activity of phosphorus in the molten slag, and a_{iron} represents the activity of phosphorus in the molten iron.
[Math. 9]

$$\Delta G_{equilibrium} = 0 \quad ...(8)$$

[0058] Further, according to Relational Expressions (7) to (8), the overpotential η generated between the electrodes, formed by the cathode 104 and the anode 105 when a current is applied to the molten iron 300 and the molten slag 200, is represented by Relational Expression (9) below. The constant α in Relational Expression (1) can be calculated by comparing Relational Expressions (6) and (9).

[0059] It should be noted that in Relational Expression (9), η represents the overpotential, R represents a gas constant, F represents the Faraday constant, Z represents the charge number, Lp represents the phosphorus distribution (-) in the molten slag at the molten steel temperature T (K), and Lp' represents the required phosphorus distribution (-).
[Math. 10]

$$\eta = \left(\frac{R}{ZF}\right) \times \ln (Lp'/Lp) \times T \quad ...(9)$$

[0060] As described above, the method for dephosphorizing molten iron according to the present embodiment includes determining the phosphorus distribution Lp (-) in the molten slag at the molten steel temperature T (K) and the required phosphorus distribution Lp' (-) in the molten slag, thereby determining the applied current density I required to achieve the phosphorus distribution Lp', using Relational Expression (1) with the constant α determined.

[0061] As described above, the invention according to the first embodiment effectively improves the phosphorus distribution, by controlling the applied current density based on the relationship among the phosphorus distribution in molten slag, the required phosphorus distribution in the molten slag, and the molten steel temperature of molten iron, thereby promoting the dephosphorization reaction of the molten iron.

[Second embodiment]

[0062] A method for dephosphorizing molten iron according to a second embodiment will be described. The method for dephosphorizing molten iron according to the present embodiment is characterized in that, in the method for dephosphorizing molten iron according to the aforementioned embodiment, the concentration [C] of carbon contained in the molten iron is 4.0 mass% or less, and the applied current density I (A/m^2) satisfies Relational Expression (2) below.
[Math. 11]

$$I \geq 5.264\times10^{-2} \ln(Lp'/Lp) \times T \quad ...(2)$$

[0063] In Relational Expression (2), I represents the applied current density (A/m^2), Lp represents the phosphorus distribution (-) in the molten slag, Lp' represents the required phosphorus distribution (-) in the molten slag, and T represents the molten steel temperature (K) of the molten iron. Hereinafter, technical features included in the method for dephosphorizing molten iron according to the present embodiment will be described.

[0064] The method for dephosphorizing molten iron according to the present embodiment employs Relational Expression (2), in which the constant α is determined to be 5.264×10^{-2} by Relational Expression (1) used in the method for dephosphorizing molten iron according to the aforementioned embodiment. That is, the method for dephosphorizing molten steel according to the present embodiment can obtain the distribution Lp' in the molten slag, by measuring the phosphorus concentration after the application of a current with the density I to the molten slag 200 and the molten iron 300, using Relational Expression (2).

[0065] In the method for dephosphorizing molten iron according to the present embodiment, a current applied to the molten slag and the molten iron is controlled based on the current value. Therefore, the method for dephosphorizing molten iron according to the present embodiment can reduce the influence on variations in the aforementioned overpotential, even when the electrical properties of the molten iron vary.

[0066] Furthermore, in the method for dephosphorizing molten steel according to the present embodiment, applying a current having a density that satisfies Relational Expression (2) to the molten slag and the molten iron can effectively improve the phosphorus distribution without modifying the molten slag.
Therefore, the method for dephosphorizing molten iron according to the present embodiment can be applied to molten iron with various component compositions.

[0067] In the method for dephosphorizing molten iron according to the present embodiment, the concentration [C] of carbon contained in the molten iron to which a current is applied is preferably 4.0 mass% or less. If the concentration [C] of carbon contained in the molten iron to which a current is applied is 4.0 mass% or less, the content of carbon that may be contained in the molten iron can be secured, which is preferable. It should be noted that the concentration [C] of carbon contained in the molten iron to which a current is applied may be 0.1 mass% or more.

[0068] Thus, the method for dephosphorizing molten iron according to the present embodiment is excellent in that it is possible to apply any concentration of carbon within the range of the concentrations of carbon that may be contained in the molten iron.

[0069] As described above, the invention according to the second embodiment effectively improves the phosphorus distribution and thus promotes the dephosphorization reaction of molten iron without being affected by factors such as change in overpotential due to variations in electrical properties of the molten iron or the concentration of components contained in the molten iron, such as the carbon concentration [C] or phosphorus concentration [P].

[Third embodiment]

[0070] A method for dephosphorizing molten iron according to a third embodiment will be described. The method for dephosphorizing molten iron according to the present embodiment is characterized in that arc discharge is not generated due to the current applied between molten slag and molten iron in the method for dephosphorizing molten iron according to each of the embodiments described above.

[0071] Hereinafter, technical features included in the method for dephosphorizing molten iron according to the present embodiment will be described.

[0072] The method for dephosphorizing molten iron according to the present embodiment is designed to perform dephosphorization of molten iron under the condition that the generation of arc discharge due to a current applied between molten slag and molten iron is prevented. That is, with the method for dephosphorizing molten iron according to the present embodiment, it is possible to effectively perform dephosphorization of molten iron by preventing the generation of arc discharge due to a current applied between molten slag and molten iron and thus promoting a reaction between phosphorus and iron oxide contained in the molten iron.

[0073] The generation of arc discharge in the molten iron dephosphorization apparatus, caused by a current applied between molten slag and molten iron, is undesirable from the perspective of promoting the dephosphorization reaction of the molten iron. The reason for adopting the condition that the generation of arc discharge due to a current applied between molten slag and molten iron is prevented in the method for dephosphorizing molten iron according to the present embodiment is described below.

[0074] In the method for dephosphorizing molten iron according to the present embodiment, as represented by Equilibrium Reaction Formula (10) below, phosphorus (P) contained in molten iron prior to dephosphorization reacts with iron oxide (FeO) contained in the molten iron to form phosphorus pentoxide, while iron oxide (FeO) contained in the molten iron prior to dephosphorization is reduced to iron (Fe). The equilibrium constant Kp in Chemical Equilibrium Reaction Formula (10) is represented by Relational Expression (11) below.

[0075]

[Chemical Formula 2] $2[P] + 5[FeO] = (P_2O_5) + 5Fe$ (10)

[Math. 12]

$$K_p = \frac{a_{P_2O_5} \cdot a^5_{Fe}}{a^2_p \cdot a^5_{FeO}} \cong \frac{a_{P_2O_5}}{a^2_p \cdot a^5_{FeO}} \ldots (11)$$

[0076] Herein, in Relational Expression (11) representing the equilibrium constant Kp, a_{P2O5} represents the activity of phosphorus pentoxide (P_2O_5) contained in the molten iron, a_{Fe} represents the activity of iron (Fe) contained in the molten iron, a_p represents the activity of phosphorus (P) contained in the molten iron, and a_{FeO} represents the activity of iron oxide (FeO) contained in the molten iron.

[0077] Note that the activity a_p of phosphorus (P) contained in the molten iron can be represented by Relational Expression (12) below, using the concentration [P] of phosphorus contained in the molten iron and its activity coefficient fp.

[Math. 13]

$$a_p = f_p[\%P] \ldots (12)$$

[0078] Further, by taking the logarithm of both sides of Relational Expression (11), which represents the equilibrium constant Kp, and rearranging the relationship among the activities of phosphorus pentoxide (P_2O_5), iron (Fe), phosphorus (P), and iron oxide (FeO) contained in the molten iron, Relational Expression (13) below is obtained.

[Math. 14]

$$\log K_p = \left(\frac{6070}{T}\right) - 16.02 \ldots (13)$$

[0079] Relational Expression (13) demonstrates that the dephosphorization reaction of molten iron, as represented by Chemical Equilibrium Reaction Formula (10), is promoted by lowering its reaction temperature T. In typical methods for dephosphorizing molten iron, the generation of arc discharge caused by a current applied between molten slag and molten iron increases the reaction temperature T of the dephosphorization reaction of molten iron.

[0080] From such a technical perspective, the method for dephosphorizing molten iron according to the present embodiment can promote a dephosphorization reaction of molten iron by preventing the generation of arc discharge due to a current applied between molten slag and the molten iron, thereby lowering the reaction temperature T.

[0081] Furthermore, Chemical Equilibrium Reaction Formula (10) and Relational Expression (11), which represents the equilibrium constant Kp, demonstrate that increasing the activity of iron oxide (FetO) in the molten iron can promote a reaction between iron oxide and phosphorus in the molten slag, thereby enhancing the dephosphorization reaction of the molten iron. In addition, decreasing the activity of phosphorus pentoxide (P_2O_5) can suppress the reverse reaction of the dephosphorization reaction of the molten iron, which occurs with the progress of the decomposition reaction of phosphorus pentoxide (P_2O_5) contained in the molten slag.

[0082] Meanwhile, according to Relational Expression (12), which represents the activity a_p of phosphorus (P) in the molten iron, the activity a_p of phosphorus (P) corresponds to the product of the concentration [P] of phosphorus in the molten iron and its activity coefficient fp. Herein, the activity coefficient fp is higher as the carbon concentration [%C] in the molten steel is higher. Therefore, increasing the carbon concentration [%C] in the molten steel and thereby enhancing the activity coefficient fp can increase the activity a_p of phosphorus (P) in the molten iron.

[0083] In the method for dephosphorizing molten iron according to the present embodiment, the value of a current applied between the molten slag and the molten iron required for preventing the generation of arc discharge is preferably 5000 (A) or less.

[0084] In the method for dephosphorizing molten iron according to the present embodiment, when the current applied between the molten slag and the molten iron is within the range of 500 to 5000 (A) or less, arc discharge is not generated. This enables a favorable energy balance in the dephosphorization reaction of the molten iron, thereby ensuring high thermal efficiency in the dephosphorization. From this technical perspective, a molten iron dephosphorization apparatus to which the method for dephosphorizing molten iron according to the present embodiment can be applied is preferably a DC electric arc furnace.

[0085] A DC electric arc furnace features low power consumption as well as low unit consumption required for electrodes and refractories, and generates low noise and flicker. Further, by installing a facility for preheating and continuously charging scrap into the DC electric arc furnace, a high-temperature exhaust gas can be utilized for preheating, preventing heat radiation that occurs when a furnace lid is opened to charge scraps into the furnace, and thereby reducing energy consumption.

[0086] In recent DC electric arc furnace designs, it has become more common to introduce a facility for preheating and continuously charging scrap and to adopt an eccentric bottom tapping method. Adopting the eccentric bottom tapping method for the DC electric arc furnace enables prompt and efficient tapping without tilting the furnace body. This configuration helps prevent slag from flowing into a ladle during tapping, which is preferable to maintain the cleanness of molten steel.

[0087] As described above, the invention according to the third embodiment effectively improves the phosphorus distribution and thus promotes the dephosphorization reaction of molten iron by preventing the generation of arc discharge, which lowers the reaction temperature T, and setting the value of the current applied between the molten slag and molten iron to 5000 (A) or less. In addition, the method for dephosphorizing molten iron according to the third embodiment can be implemented using a DC electric arc furnace.

[Fourth embodiment]

[0088] A method for dephosphorizing molten iron according to a fourth embodiment will be described. The method for dephosphorizing molten iron according to the present embodiment is characterized in that the liquid phase ratio of molten slag in the method for dephosphorizing molten iron according to each of the embodiments described above is 60 vol.% or greater. Hereinafter, technical features included in the method for dephosphorizing molten iron according to the present embodiment will be described.

[0089] In the method for dephosphorizing molten iron according to the present embodiment, the molten slag 200 is formed within the molten iron dephosphorization apparatus 100, such as a refining reaction vessel, into which the molten iron 300 (molten metal) is charged. At this time, the molten slag 200 is added to the upper surface of the molten iron 300 such that the molten slag 200 has a thickness that allows the cathode 104 to be immersed in only the molten slag 200. As the cathode 104, an electrode made of a conductive material is immersed in only the molten slag 200.

[0090] In the method for dephosphorizing molten iron according to the present embodiment, the molten slag 200 employed for dephosphorization of the molten iron 300 preferably contains components such as CaO, SiO_2, FeO, and MgO, which are commonly used in dephosphorization refining. As is evident from Relational Expressions (1) and (2), the method for dephosphorizing molten iron according to the present embodiment enables the required phosphorus distribution in the molten slag 200 to increase without specifying the component composition of the molten slag 200.

[0091] In the method for dephosphorizing molten iron according to the present embodiment, the cathode 104 provided in the molten iron dephosphorization apparatus 100 is required to be immersed exclusively in the molten slag 200 and the liquid phase ratio of the molten slag 200 is preferably 60 vol.% or greater to increase the dephosphorization reaction efficiency. The liquid phase ratio of the molten slag 200 may be set to any value, provided that the cathode 104 and the anode 105, which are employed to apply a current between the molten slag 200 and the molten iron, can be inserted into

the molten slag 200. The liquid phase ratio of the molten slag 200 is preferably 60 vol.% or greater, as this allows the cathode 104 to be sufficiently immersed in the molten slag 200, thereby promoting the dephosphorization reaction of the molten iron. The liquid phase ratio of the molten slag 200 is preferably 95 vol.% or less, as this facilitates easier operation of the molten iron dephosphorization apparatus 100. It should be noted that the liquid phase ratio of the molten slag 200 refers to the percentage of the liquid phase present in the molten slag 200.

[0092] As described above, with the invention according to the fourth embodiment, it is possible to allow the cathode of the molten iron dephosphorization apparatus to be sufficiently immersed in molten slag, and thus effectively improve the phosphorus distribution and promote a dephosphorization reaction of molten iron by setting the liquid phase ratio of the molten slag to 60 vol.% or greater.

[Other embodiments]

[0093] Although the invention of the present application has been described above with reference to the embodiments, the invention of the present application is not limited thereto. The configuration and the details of the invention of the present application may be changed in various ways as can be understood by those skilled in the art within the technical scope of the invention of the present application. In addition, a program, a system, or an apparatus that includes any combination of the features included in the respective embodiments is encompassed by the technical scope of the present invention.

Examples

[0094] Hereinafter, the advantageous effects of the present invention will be specifically described based on Examples, but the present invention is not limited thereto.

(Example 1 of the invention)

[0095] Dephosphorization of molten iron was performed in an electric furnace facility using the method for dephosphorizing molten iron according to the present embodiment. Specifically, scrap, iron phosphide (FeP), carbonaceous material, and CaO-SiO_2-FeO-MgO-based slag were charged into an electric furnace in the electric furnace facility. The molten steel raw materials were then melted using an AC arc. Consequently, 300 tons of molten steel and 30 kg/molten steel-t of molten slag were obtained within the electric furnace.

[0096] Thereafter, a graphite electrode used for the AC arc above the furnace was immersed in the molten slag to serve as a cathode. A core metal portion of a gas-stirring lance was immersed in the molten steel to serve as an anode. Dephosphorization of the molten steel was performed (Level 1) by applying a DC current, with an average current density of 300 (A/m^2) and an applied current value of 2100 (A) between the molten slag and the molten steel, for 30 minutes while blowing an argon gas (Ar) at 2.0 Nm^3/min through the gas-stirring lance.

[0097] During the dephosphorization of the molten steel, samples of the molten steel were collected at the following time points: before the dephosphorization (0 minutes), 10 minutes after the start of the dephosphorization, 20 minutes after the start of the dephosphorization, and 30 minutes after the start of the dephosphorization (upon the completion of dephosphorization). The phosphorus concentration in the molten steel was measured to determine the phosphorus distribution (actual phosphorus distribution). Table 1 presents the phosphorus distribution at each time point during the dephosphorization of the molten steel, along with the composition ratio of the slag. Table 1 also presents the slag liquid phase ratio as well as whether the relationship represented by Relational Expression (2) above is satisfied. It should be noted that in Invention Example 1, the required phosphorus distribution for the molten slag was set to 100.

[0098] In addition, regarding the method for dephosphorizing molten iron according to Example 1 of the invention, whether an arc was generated was confirmed, and the value of the current applied between the molten slag and the molten steel was set to a predetermined current value.

(Examples 2 to 6 of the invention)

[0099] In Invention Examples 2 to 5, dephosphorization of molten steel was performed (Levels 2 to 5) in the same manner as in Invention Example 1, except that the average current density of the DC current applied between the molten slag and molten steel was varied within the range of 300 to 350 (A/m^2) and the applied current value was varied within the range of up to 5000 (A).

[0100] Meanwhile, in Invention Example 6, arc discharge was generated (Level 9) by setting the average current density of the DC current applied between the molten slag and molten steel to 3000 (A/m^2), and setting the applied current value to 21000 (A).

[0101] Table 1 presents the phosphorus distribution (actual phosphorus distribution) at each processing time during the

dephosphorization of the molten steel, and the composition ratio of the slag. Table 1 also shows the slag liquid phase ratio as well as whether the relationship represented by Relational Expression (2) above is satisfied. Regarding each of the methods for dephosphorizing molten iron according to Examples 2 to 6 of the invention, whether an arc was generated was confirmed, and the value of a current applied between the molten slag and the molten steel was set to a predetermined current value.

(Comparative Examples 1 to 2)

[0102] Dephosphorization of molten steel was performed (Level 6) under the same conditions as in Invention Example, except that no DC current was applied between molten slag and molten steel. Dephosphorization of molten steel was also performed (Level 7) under the condition in which Relational Expression (2) above was not satisfied, by setting the average current density of a DC current applied between molten slag and molten steel to 200 (A/m^2). Table 1 presents the phosphorus distribution (actual phosphorus distribution) at each time point during the dephosphorization of the molten steel, along with the composition ratio of the slag. Table 1 also shows the slag liquid phase ratio and indicates whether the relationship represented by Relational Expression (2) above is satisfied.

(Comparative Example 3)

[0103] Dephosphorization of molten steel was performed (Level 8) under the same conditions as in Invention Example 1, except that no DC current was applied between molten slag and molten steel. Table 1 presents the phosphorus distribution (actual phosphorus distribution) at each time point during the dephosphorization of the molten steel, along with the composition ratio of the slag. Table 1 also shows the slag liquid phase ratio and indicates whether the relationship represented by Relational Expression (2) above is satisfied.

[Table 1]

Level	Average Current Density I (A/m^2)	Applied Current Value (A)	Whether Relational Expression (2) is Satisfied	[C] mass% Before Molten Iron is Processed	Actual Phosphorus Distribution			Required Phosphorus Distribution	Composition Ratio of Slag (C/S+A)	Liquid Phase Ratio (%) of Molten Slag	Whether Arc is Generated	Remarks
					10 min	20 min	30 min					
1	300	2100	Satisfied	0.01	40.8	85.9	113.4	100	0.8	100	Not Generated	Invention Example 1
2	350	2450	Satisfied	0.01	57.4	160.4	264.7	100	0.8	100	Not Generated	Invention Example 2
3	300	2100	Satisfied	0.01	30.1	55.3	77.5	100	1.5	60	Not Generated	Invention Example 3
4	300	2100	Satisfied	2.00	40.2	83.6	110.0	100	0.8	100	Not Generated	Invention Example 4
5	300	2100	Satisfied	4.00	39.8	83.7	108.2	100	0.8	100	Not Generated	Invention Example 5
9	3000	21000	Satisfied	0.01	4.0	5.1	5.5	100	0.8	100	Generated	Invention Example 6
6	0	0	Not Satisfied	0.01	4.1	5.5	6.0	100	0.8	100	Not Generated	Comparative Example 1
7	200	1400	Not Satisfied	0.01	22.7	37.6	44.0	100	0.8	100	Not Generated	Comparative Example 2
8	-	-	-	0.01	-	-	-	100	3.0	30	Not Generated	Comparative Example 3*
*Note: The electrodes were not immersible.												

[0104] Table 1 presents the test conditions and the results of each level used in Invention Examples 1 to 6 and Comparative Examples 1 to 3. Table 1 also shows the required phosphorus distribution, which is used to evaluate whether the calculated actual phosphorus distribution reached the required phosphorus distribution. As is evident from Table 1, under the conditions where the slag liquid phase ratio is 100% (Invention Examples 1 to 2 and 4 to 6), the calculated actual phosphorus distribution (i.e., phosphorus distribution obtained from the experiment results) did not reach the required phosphorus distribution under the conditions when Relational Expression (2) above was not satisfied (Comparative Example 2).

[0105] Meanwhile, under the conditions where the slag liquid phase ratio was 100% (Invention Examples 1 to 2 and 4 to 6), the required level of phosphorus distribution was achieved when a DC current with a current density that satisfies Relational Expression (2) above was applied (Invention Examples 1 to 6).

[0106] Further, Invention Examples 1 to 5 demonstrate that the required level of the phosphorus distribution could be achieved with high efficiency when the applied current value was set to 5000 (A) or less to thereby prevent the generation of arc discharge. From this technical perspective, it has been clarified that the method for dephosphorizing molten iron according to the present embodiment can be more favorably performed using a DC electric arc furnace capable of preventing the generation of arc discharge.

[0107] Further, as the average current density of a DC current applied to the molten steel increases, the time taken to reach the required level of phosphorus distribution decreases, thereby shortening the processing time of the dephosphorization. Meanwhile, under the conditions where the slag liquid phase ratio is 30%, solidified slag obstructs the immersion of electrodes, making it difficult to apply the method for dephosphorizing molten iron according to the present invention (Comparative Example 3).

[0108] It should be noted that electrodes can be immersed into the molten slag when the slag liquid phase ratio is 60 vol.% or greater. Moreover, the slag liquid phase ratio is preferably 60 vol.% or greater from the perspective of increasing the efficiency of dephosphorization reactions. It should also be noted that this tendency is independent of the concentration [C] of carbon or the concentration [P] of phosphorus, each contained in the molten iron.

[0109] As described above, the method for dephosphorizing molten iron according to the present invention achieves the required level of phosphorus distribution under the conditions where the slag liquid phase ratio is set to 60 vol.% or greater and a DC current with a current density that satisfies Relational Expression (2) above is applied. That is, it has been clarified that applying the method for dephosphorizing molten iron according to the present invention under predetermined conditions can effectively improve the phosphorus distribution, thereby promoting the dephosphorization reaction of molten iron.

Industrial Applicability

[0110] With the method for dephosphorizing molten iron according to the present invention, it is possible to effectively improve the phosphorus distribution and thereby promote the dephosphorization reaction of molten iron without modifying the slag. This contributes to the advancement of the steel industry and is therefore highly advantageous from an industrial perspective.

Reference Signs List

[0111]

100 molten iron dephosphorization apparatus
101 MgO crucible
102 refractory ramming mix
103 induction melting furnace
104 cathode (graphite electrode)
105 anode (MgO-C electrode)
106 DC power supply
107 cable
108 heat-insulating board
200 molten slag
300 molten iron

Claims

1. A method for dephosphorizing molten iron, comprising:

applying a current between molten slag and molten iron via two electrodes, with one electrode in contact with the molten iron serving as an anode and the other in contact with only the molten slag serving as a cathode,
characterized in that
a density I of the applied current satisfies Relational Expression (1) below, in relation to a molten steel temperature T of the molten iron, a phosphorus distribution LP in the molten slag, and a required phosphorus distribution LP' in the molten slag:
[Math. 1]

$$I \geq \alpha \times \ln(Lp'/Lp) \times T \quad ...(1),$$

where, in Relational Expression (1), I represents the density (A/m^2) of the applied current, α represents a constant, LP represents the phosphorus distribution (-) in the molten slag, LP' represents the required phosphorus distribution (-) in the molten slag, and T represents the molten steel temperature T (K) of the molten iron.

2. The method for dephosphorizing molten iron according to claim 1, wherein

a concentration [C] of carbon contained in the molten iron is 4.0 mass% or less, and
the density I (A/m^2) of the applied current satisfies Relational Expression (2) below:
[Math. 2]

$$I \geq 5.264 \times 10^{-2} \ln(Lp'/Lp) \times T \quad ...(2),$$

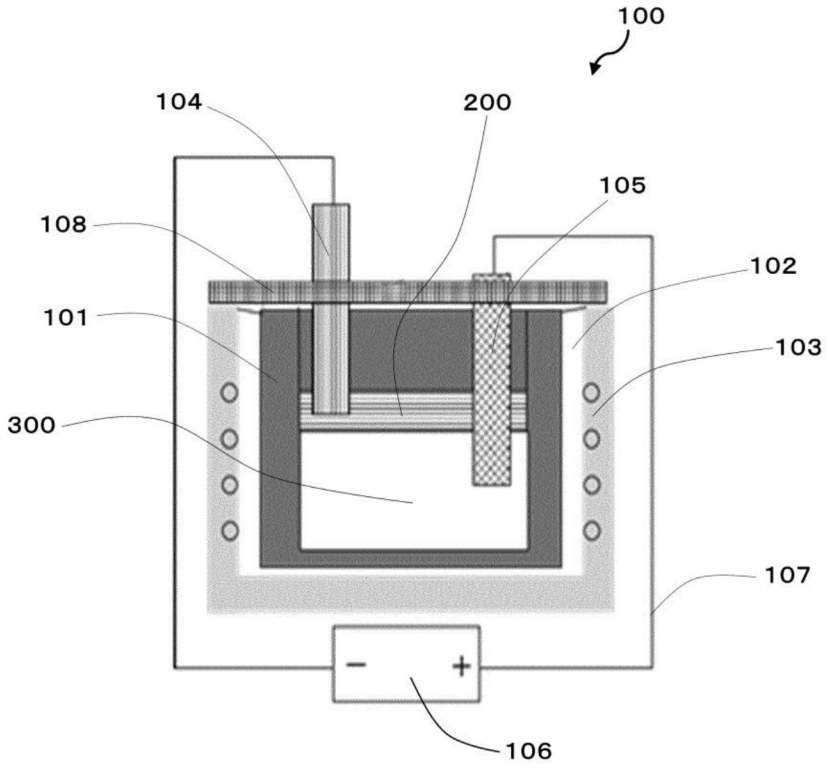
where in Relational Expression (2), I represents the density (A/m^2) of the applied current, Lp represents the phosphorus distribution (-) in the molten slag, Lp' represents the required phosphorus distribution (-) in the molten slag, and T represents the molten steel temperature (K) of the molten iron.

3. The method for dephosphorizing molten iron according to claim 1 or 2, wherein
arc discharge is not generated by applying a current between the molten slag and the molten iron.

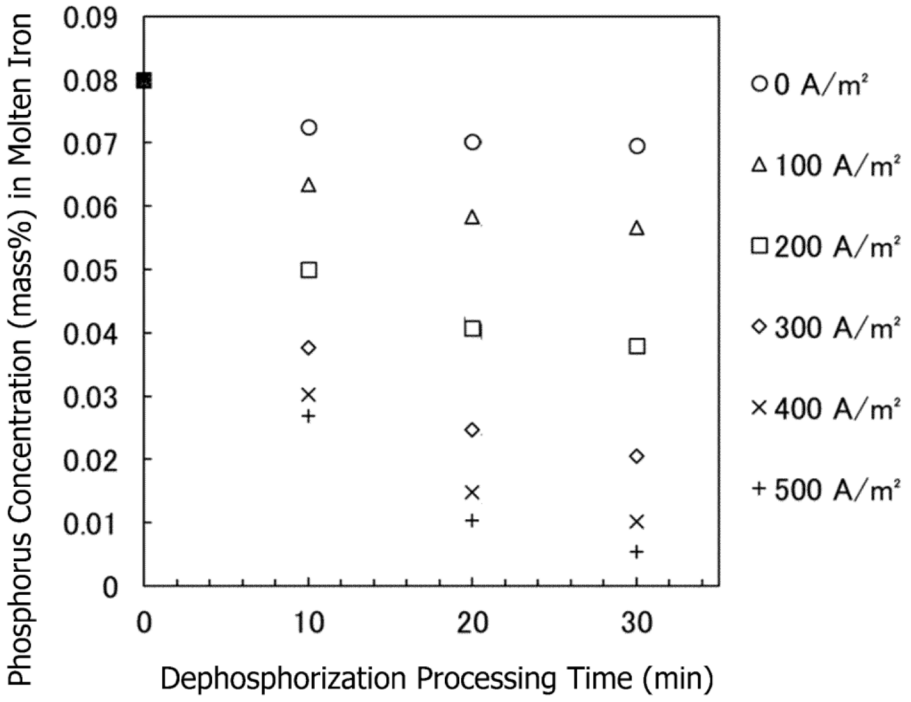
4. The method for dephosphorizing molten iron according to claim 3, wherein
a value of the current is 5000 (A) or less.

5. The method for dephosphorizing molten iron according to claim 1 or 2, wherein
a liquid phase ratio of the molten slag is 60 vol.% or greater.

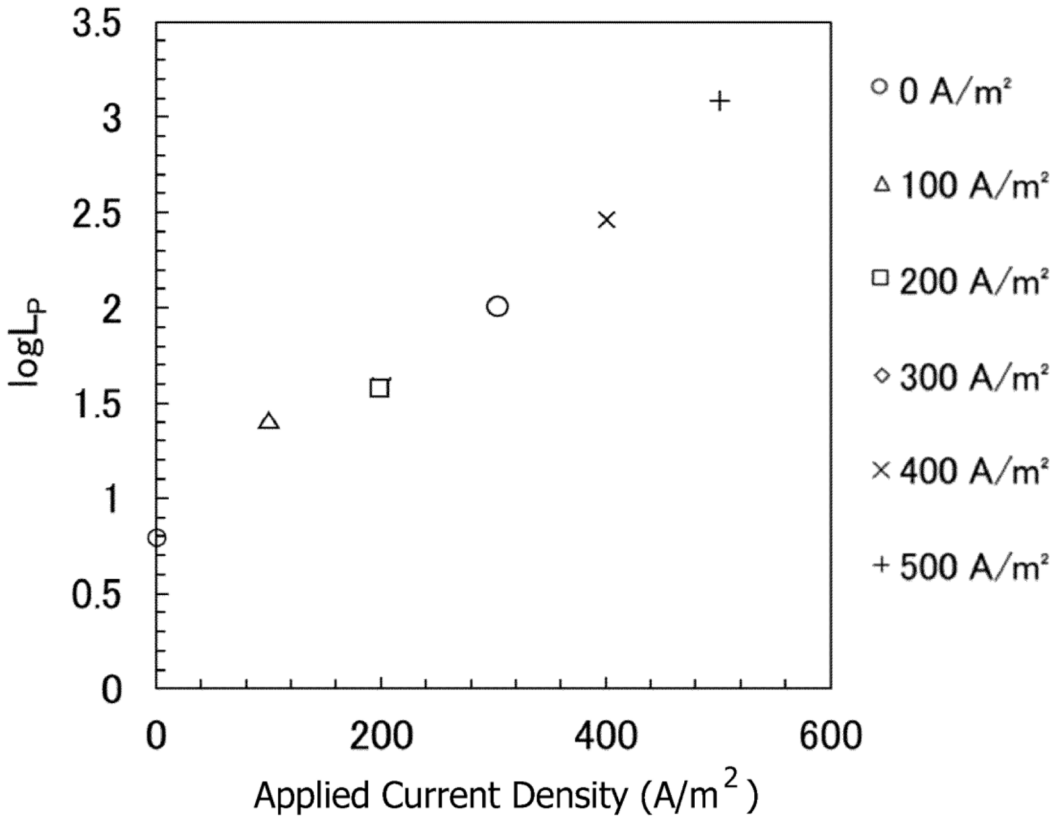
[Fig. 1]


100
104
200
105
108
102
101
103
300
107
106

[Fig. 2]


Phosphorus Concentration (mass%) in Molten Iron
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
10
20
30
Dephosphorization Processing Time (min)
○ 0 A/m²
△ 100 A/m²
□ 200 A/m²
◇ 300 A/m²
× 400 A/m²
+ 500 A/m²

[Fig. 3]


3.5
3
2.5
2
1.5
1
0.5
0
logLP
0
200
400
600
Applied Current Density (A/m2)
0 A/m²
100 A/m²
200 A/m²
300 A/m²
400 A/m²
500 A/m²

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2024/012594

A. CLASSIFICATION OF SUBJECT MATTER

C21C 1/02(2006.01)i; ***C21C 7/064***(2006.01)i; *C21C 7/00*(2006.01)n
FI: C21C1/02 110; C21C7/064 A; C21C7/00 E

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)

C21C1/02; C21C7/064; C21C7/00

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 1971-2024
Registered utility model specifications of Japan 1996-2024
Published registered utility model applications of Japan 1994-2024

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 02-182821 A (NIPPON STEEL CORPORATION) 17 July 1990 (1990-07-17) entire text	1-5
A	JP 58-185732 A (JAPAN METALS & CHEMICALS CO., LTD.) 29 October 1983 (1983-10-29) entire text	1-5
A	JP 58-185712 A (JAPAN METALS & CHEMICALS CO., LTD.) 29 October 1983 (1983-10-29) entire text	1-5

☐ 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
"D" document cited by the applicant in the international application
"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	Date of mailing of the international search report
02 May 2024	**21 May 2024**
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.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2024/012594

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 02-182821 A	17 July 1990	(Family: none)	
JP 58-185732 A	29 October 1983	(Family: none)	
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REFERENCES CITED IN THE DESCRIPTION

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