

## DESCRIPTION

### TITLE

#### METHOD OF PRODUCING REDUCED IRON

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### TECHNICAL FIELD

**[0001]** The present disclosure relates to a method of producing reduced iron.

### BACKGROUND

10 **[0002]** In recent years, there has been a strong demand for energy savings in steelworks against the backdrop of global environmental issues and fossil fuel depletion issues. The raw material of iron is mainly iron oxide, and a reduction process to reduce this iron oxide is essential in steelworks. The most widespread and common reduction process worldwide uses a blast furnace. In  
15 a blast furnace, coke or pulverized coal reacts with oxygen in hot blast (air heated to about 1200 °C) from a tuyere. This reaction produces CO and H<sub>2</sub> as reducing gases, which are used to reduce the iron ore and the like in the furnace. Recent improvements in blast furnace operation technology have decreased the reducing agent rate (the amount of coke and pulverized coal used per tonne of  
20 hot metal produced) to about 500 kg/t, and the reducing agent rate has already almost reached a lower limit. Therefore, no further significant decrease in the reducing agent rate is expected.

**[0003]** On the other hand, in regions where natural gas is produced, a vertical reduction furnace (hereinafter also referred to as a shaft furnace) is often used  
25 to produce reduced iron. In this method, the reduction furnace is charged with sintered ore, pellets, or other agglomerated iron ore as the iron oxide raw material (hereinafter also simply referred to as iron oxide). Reducing gas including CO and H<sub>2</sub> is then blown into the reduction furnace to reduce the iron oxide to produce reduced iron. In this method, natural gas or the like is  
30 used as the feed gas for the reducing gas. This feed gas is heated and reformed together with top gas in a reformer. This produces reducing gas. Here, the top gas is gas after the iron oxide is reduced in the reduction furnace, and is typically discharged from the top of the reduction furnace. The reducing gas is blown into the reduction furnace and reacts with iron oxide supplied from the  
35 top of the furnace. The iron oxide is then reduced to reduced iron. The reduced iron is then cooled in a region below where the reducing gas is blown into the

reduction furnace, and then discharged from the bottom of the reduction furnace.

5 [0004] Further, as mentioned above, the top gas, which is gas after iron oxide is reduced, is discharged from the reduction furnace, for example, from the top of the furnace. After dust collection and cooling is applied to the top gas, some is fed to the reformer as raw material for reformed gas. Further, remaining top gas is used as fuel gas for the reformer. In this method, the top gas used as fuel gas for the reformer is normally discharged out of the system.

10 [0005] As such a reduced iron production process, for example, Patent Literature (PTL) 1 describes a method of producing reduced iron by reforming exhaust gas from a reduction furnace and natural gas in a reformer to produce reducing gas consisting mainly of CO and H<sub>2</sub>, blowing the reducing gas into the reduction furnace, and reducing iron oxide in the reduction furnace.

15 [0006] Further, PTL 2 describes a method of producing reduced iron by reforming coke oven gas and CO<sub>2</sub>-removed top gas from a reduction furnace to produce reducing gas, which is then blown into a reduction furnace.

#### CITATION LIST

##### Patent Literature

20 [0007] PTL 1: JP 2017-088912 A  
PTL 2: JP 6190522 B2

#### SUMMARY

##### (Technical Problem)

25 [0008] The method described in PTL 1 uses externally supplied natural gas for the production of reducing gas. Therefore, although lower than that of blast furnaces, there is a problem that a certain amount of CO<sub>2</sub> emissions are unavoidable.

30 [0009] Further, the method described in PTL 2 uses coke oven gas or converter gas produced in a steelworks to produce reducing gas. Here, in an integrated steelworks, coke oven gas and converter gas are needed as fuel gas for downstream processes such as a heating furnace and an annealing furnace. Therefore, when coke oven gas or converter gas is diverted to the reduced iron production process, a fuel gas shortage is caused in the downstream processes. 35 As a result, natural gas is supplied from outside to compensate for the shortage of fuel gas in the downstream processes. That is, even with the method

described in PTL 2, energy savings and a decrease in CO<sub>2</sub> emissions could not both be achieved, and the problem remained.

[0010] In view of the circumstances described, it would be helpful to provide a method of producing reduced iron that can realize both energy savings and a 5 decrease in CO<sub>2</sub> emissions.

(Solution to Problem)

[0011] The inventors have conducted extensive research to realize both energy savings and a decrease in CO<sub>2</sub> emissions, and developed a system that 10 circulates and reuses top gas.

That is, the inventors developed  
a top gas circulation and reuse system (hereinafter also simply referred to a circulation system) comprising:  
a blowing process of blowing reducing gas into a reduction furnace;  
15 a reduction process, in the reduction furnace, of reducing iron oxide by the reducing gas to obtain reduced iron;  
a distribution process of distributing top gas discharged from the reduction furnace into a first top gas and a second top gas;  
a generation process of generating regenerative carbon monoxide gas 20 by an electrolytic reaction using the first top gas; and  
a heating process of heating a mixed gas of the regenerative carbon monoxide gas and the second top gas to become reducing gas.

[0012] The inventors further investigated and made the following discoveries.

- In the circulation system described above, the amount of gas introduced into the distribution process, the generation process, and the heating process is controlled according to a CO<sub>2</sub> conversion rate  $\eta_C$  [-] (hereinafter also simply referred to as the CO<sub>2</sub> conversion rate) due to the electrolysis reaction in the generation process (that is, the reaction to reform CO<sub>2</sub> in the first top gas to CO by electrolysis).
- This allows the production of reduced iron with high operational stability without the need for extra energy input, that is, production achieving both further energy savings and a decrease in CO<sub>2</sub> emissions.

The present disclosure is based on these discoveries and further studies.

[0013] Primary features of the present disclosure are as follows.

35 [0014] 1. A method of producing reduced iron, the method comprising:  
a charging process of charging iron oxide into a reduction furnace;

a blowing process of blowing reducing gas into the reduction furnace;  
a reduction process, in the reduction furnace, of reducing the iron oxide  
by the reducing gas to obtain reduced iron;

5 a distribution process of distributing top gas discharged from the  
reduction furnace into a first top gas and a second top gas;

a generation process of generating regenerative carbon monoxide gas  
by an electrolytic reaction using the first top gas; and

a heating process of heating a mixed gas of the regenerative carbon  
monoxide gas and the second top gas to become the reducing gas, wherein

10 an amount of gas introduced into the distribution process, the  
generation process, and the heating process is controlled according to a  $CO_2$   
conversion rate  $\eta_C$  from the electrolytic reaction in the generation process.

[0015] 2. The method of producing reduced iron according to 1, above,  
wherein the amount of gas introduced into the distribution process, the  
15 generation process, and the heating process is controlled so as to satisfy the  
following Expression (1),

[Math 1]

$$1 - \frac{V_{CO_2}}{W_{CO_2}} \leq \eta_C \quad \dots(1)$$

where

20  $W_{CO_2}$  is an amount of  $CO_2$ , in  $Nm^3/t$ , contained in the top gas  
introduced into the distribution process, and

$V_{CO_2}$  is an amount of  $CO_2$ , in  $Nm^3/t$ , contained in the gas introduced  
into the heating process.

[0016] 3. The method of producing reduced iron according to 1 or 2, above,  
25 wherein, in the distribution process, the top gas is separated into separated  
carbon dioxide gas and remaining gas,

the separated carbon dioxide gas is distributed as the first top gas, and  
the remaining gas is distributed as the second top gas.

30 (Advantageous Effect)

[0017] According to the present disclosure, it is possible to operate with high  
operational stability and achieve both further energy savings and a decrease in  
 $CO_2$  emissions in the production of reduced iron.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0018] In the accompanying drawings:

FIG. 1 is a diagram illustrating a conventional reduced iron production process; and

5 FIG. 2 is a diagram illustrating an example of a reduced iron production process according to a method of producing reduced iron according to an embodiment of the present disclosure.

## DETAILED DESCRIPTION

10 [0019] The following is a description of a method of producing reduced iron according to an embodiment of the present disclosure, with reference to the drawings.

15 [0020] First, a conventional reduced iron production process (hereinafter also referred to as a conventional production process) is described. FIG. 1 is a schematic diagram illustrating an example of a conventional production process. In the drawing, reference sign 1 is a reduction furnace, 1a is iron oxide, 1b is reduced iron, 3 is a deduster, 4 is a dehydrator, 5 is a natural gas supply, 6 is an air supply, 7 is a reformer, and 9 is a reducing gas blowing device.

20 [0021] In the example of a conventional production process, iron oxide is charged from the top of the reduction furnace and gradually descends. There, iron oxide is reduced by blowing in high-temperature reducing gas from a central portion of the reduction furnace. The reduced iron is then discharged from the bottom of the reduction furnace. In this process, top gas containing mainly CO, CO<sub>2</sub>, H<sub>2</sub>, and H<sub>2</sub>O is discharged from the top of the reduction furnace. The top gas is de-dusted by the deduster, and a portion is subjected to moisture adjustment and fed to the reformer as feed gas. Gas containing hydrocarbons, for example, natural gas from a natural gas supply, is supplied to the reformer along with the top gas that has been subjected to moisture adjustment. The supplied gas is then heated in the reformer. A reforming reaction then occurs, producing high-temperature reducing gas containing mainly CO and H<sub>2</sub>. This reducing gas is then blown into the reduction furnace. Further, the remaining portion of the top gas is dehydrated and used as fuel for heating in the combustion chamber of the reformer. After combustion as fuel for heating, the top gas still containing CO<sub>2</sub> is normally discharged out of the system. When reduced iron is produced using this example of a conventional production process, approximately a little more than 1 tonne of CO<sub>2</sub> is

discharged out of the circulation system when 1 tonne of reduced iron is produced.

[0022] In contrast, in the method of producing reduced iron according to an embodiment of the present disclosure, as illustrated in FIG. 2 for example, the 5 top gas discharged from the reduction furnace is distributed into first top gas and second top gas in a top gas distributor. Then, in a carbon monoxide generator, regenerative carbon monoxide gas is generated by an electrolytic reaction using the first top gas. The regenerative carbon monoxide gas and the second top gas are then mixed to form a mixed gas. The mixed gas is then 10 heated in a heating apparatus. The heated mixed gas, as reducing gas, is then blown into the reduction furnace from the reducing gas blowing device. In the drawing, reference sign 10 is a water vapor supply, 11 is the carbon monoxide generator, 12 is the heating apparatus, 13 is a heat source, and 14 is the top gas distributor.

15 The following is a description of each process of the method of producing reduced iron according to an embodiment of the present disclosure. The charging process, blowing process, and reduction process can be carried out in accordance with conventional methods, for example, in the same manner as in the conventional process described above, and therefore description is 20 omitted here.

### [0023] • Distribution Process

In the distribution process, for example, the top gas discharged from the reduction furnace is distributed into the first top gas and the second top gas in the top gas distributor. Further, distribution of the top gas and a flow rate 25 controller are not particularly limited and may follow a conventional method. For example, a mass flow controller or the like may be used.

[0024] In the distribution process, the top gas may be distributed in its original composition. Further, for example, certain gas types, such as CO<sub>2</sub>, may be separated and distributed as follows. That is, the top gas may be separated into 30 separated carbon dioxide gas and remaining gas (CO<sub>2</sub> separation), and the separated carbon dioxide gas may be distributed as the first top gas and the remaining gas as the second top gas.

[0025] The method of CO<sub>2</sub> separation is not particularly limited, and various methods may be used, examples including chemical absorption, physical 35 absorption, adsorption separation, membrane separation, deep cold separation, oxygen combustion, chemical loop combustion, and the like. Among these, in

particular, chemical absorption methods, of which an amine absorption method is representative, and adsorption separation methods, of which a PSA method is representative, have long been used in chemical plants, industrial CO<sub>2</sub> production, and the like. Further, these methods have a track record of 5 recovering gas with a CO<sub>2</sub> concentration of 99 vol% or more. These methods are therefore preferred. The CO<sub>2</sub> concentration in the separated carbon dioxide gas is preferably 90 vol% or more. The CO<sub>2</sub> concentration in the separated carbon dioxide gas may be 100 vol%.

[0026] The composition of the remaining gas distributed as the second top gas 10 varies depending on the amount of CO<sub>2</sub> separated and may be, for example, CO: 5 vol% to 70 vol%, CO<sub>2</sub>: 0 vol% to 25 vol%, H<sub>2</sub>: 25 vol% to 75 vol%, H<sub>2</sub>O: 0 vol% to 50 vol%, with the balance being: 0 vol% to 30 vol%.

[0027] When the top gas is distributed in the distribution process into the first 15 top gas and the second top gas with the same composition, there may optionally be a separation process between the distribution process described above and the generation process described below to separate specific gas types such as CO<sub>2</sub> from the first top gas and the second top gas.

For example, as described above, the first top gas may be separated 20 into separated carbon dioxide gas and remaining gas (CO<sub>2</sub> separation), and the separated carbon dioxide gas may be used as the first top gas in the generation process. The remaining gas described above may be merged directly into the second top gas.

[0028] Further, from the viewpoint of controlling the flow rate of the top gas introduced into the distribution process, a portion of the top gas may be used 25 as fuel for a heating apparatus or the like. For example, a portion of the top gas is burned in a combustion chamber of a heating apparatus using oxygen supplied from an oxygen supply, such as pure oxygen generated by a deep cold separation process driven by CO<sub>2</sub>-free electrical power. Further, the top gas after combustion may be dehydrated as required before being returned to the 30 original line.

#### [0029] • Generation process

In the generation process, for example, regenerative carbon monoxide gas is generated in a carbon monoxide generator by an electrolytic reaction using the first top gas distributed in the distribution process described above. 35 CO is generated, for example, by electrolysis of CO<sub>2</sub> contained in the first top gas, according to the reaction equation in the following Expression (i).



5 [0030] Further, when  $\text{H}_2\text{O}$  is included in the first top gas or when water vapor is introduced together with the first top gas,  $\text{H}_2\text{O}$  is preferably electrolyzed at the same time as  $\text{CO}_2$ . In this case,  $\text{H}_2$  is produced according to the reaction equation in the following Expression (ii).



The simultaneous electrolysis of  $\text{CO}_2$  and  $\text{H}_2\text{O}$  according to Expressions (i) and (ii) is hereinafter also referred to as a co-electrolysis reaction.

10 [0031] That is, in the reduction furnace,  $\text{CO}$  and  $\text{H}_2$  are consumed and become  $\text{CO}_2$  and  $\text{H}_2\text{O}$  in the reduction reaction of iron oxide. Therefore, when comparing the composition of the reducing gas blown into the reduction furnace with that of the top gas discharged from the reduction furnace,  $\text{CO}$  and  $\text{H}_2$  decrease, while  $\text{CO}_2$  and  $\text{H}_2\text{O}$  increase. Therefore, from the viewpoint of 15 maintaining the composition of the reducing gas within a certain range in the circulation system described above, it is preferable to carry out a co-electrolysis reaction to adjust fluctuating amounts of not only  $\text{CO}$  but also  $\text{H}_2$ .

[0032] Electrolysis conditions of  $\text{CO}_2$  and  $\text{H}_2\text{O}$  and the like are not particularly limited, and a conventional method may be followed.

20 [0033] Further, when the separated carbon dioxide gas obtained in the distribution process or the separation process described above is used, the composition of the first top gas is the same as that of the separated carbon dioxide gas. When the top gas is distributed in the distribution process with its original composition and no separation process is carried out, the composition 25 of the first top gas is basically the same as the composition of the top gas introduced in the distribution process. In such a case, the composition of the first top gas is, for example,  $\text{CO}$ : 5 vol% to 50 vol%,  $\text{CO}_2$ : 5 vol% to 30 vol%,  $\text{H}_2$ : 5 vol% to 80 vol%,  $\text{H}_2\text{O}$ : 0 vol% to 35 vol%, with the balance being: 0 vol% to 20 vol%. The composition of the second top gas, described below, is 30 similar.

[0034] In addition to the first top gas, any other gas containing  $\text{CO}_2$  (hereinafter referred to as "other gas") may be used in the generation process. Examples of the other gas include by-product gas of a steelmaking process, specifically blast furnace gas (BFG) and coke oven gas (COG). Further, the 35 other gas may be introduced into the separation process described above along with the first top gas and separated into separated carbon dioxide gas and

remaining gas before supplying the separated carbon dioxide gas to the generation process.

[0035] Further, in the generation process, water vapor may be introduced along with the first top gas in consideration of the mass balance of the entire circulation system. Water vapor may, for example, be supplied into a first top gas flow line before being introduced into the carbon monoxide generator, or may be introduced directly into the carbon monoxide generator from an independent line. Water vapor may be supplied from outside the circulation system described above, or H<sub>2</sub>O removed by a dehydrator may be reused.

5 [0036] In addition, from the point of view of electrolysis efficiency, the following is preferred. The top gas is separated into separated carbon dioxide gas and remaining gas (CO<sub>2</sub> separation) in the distribution process. The separated carbon dioxide gas is then introduced into the generation process as the first top gas, and water vapor is introduced into the generation process. The 15 remaining gas becomes the second top gas.

[0037] Electrolysis apparatus used as a carbon monoxide generator is not particularly limited, and typically used apparatus may be used. Further, the electrical power used for electrolysis is also not particularly limited. Electrical power used for electrolysis is preferably CO<sub>2</sub>-free electrical power, for 20 example electrical power supplied by solar power or wind power.

25 [0038] It is not desirable that a large amount of H<sub>2</sub>O be introduced into the heating process described below. Therefore, while considering the mass balance of the circulation system as a whole, it is preferable to dehydrate the regenerative carbon monoxide gas using a dehydrator, as appropriate, prior to the heating process described below.

[0039] Further, the composition of the regenerative carbon monoxide gas is not particularly limited. In regenerative carbon monoxide gas from which H<sub>2</sub>O is removed, for example, after dehydration by the dehydrator, the composition is CO: 1 vol% to 60 vol%, H<sub>2</sub>: 40 vol% to 99 vol%, with the balance being: 0 30 vol% to 30 vol%.

[0040] Oxygen obtained as an auxiliary material of carbon monoxide generation is separated from the gas in the circulation system described above. That is, gas (regenerative carbon monoxide gas) and oxygen in the circulation system are normally already separated in the carbon monoxide generator.

35 Therefore, there is no particular need to provide an oxygen separator, but this does not restrict installation of a separator. Separated oxygen can be released

to the air, but is preferably used for other purposes as appropriate, such as oxygen for combustion for gas heating in the circulation system described above, to supplement the oxygen requirements of other processes in and outside the steelworks, and the like.

5 [0041] • Heating process

In the heating process, a mixture of the regenerative carbon monoxide gas and the second top gas (hereinafter also referred to as mixed gas) is heated to obtain reducing gas. Mixing of the regenerative carbon monoxide gas and the second top gas may be done upstream of the heating apparatus as illustrated 10 in FIG. 2, or may be carried out in the heating apparatus by supplying these gases directly to the heating apparatus from independent lines. In FIG. 2, the second top gas is supplied to the regenerative carbon monoxide gas flow line between the dehydrator and the heating apparatus, but this is not a limitation. For example, the second top gas may be supplied into the regenerative carbon 15 monoxide gas flow line between the carbon monoxide generator and the dehydrator.

[0042] The gas composition of the reducing gas (mixed gas) is, for example, CO: 1 vol% to 60 vol%, H<sub>2</sub>: 40 vol% to 99 vol%, with the balance being 0 vol% to 30 vol%.

20 [0043] The heating temperature and heating method of the reducing gas (mixed gas) are not particularly limited and may be in accordance with a conventional method. For example, heating temperature for the reducing gas (mixed gas) may be from 750 °C to 1100 °C.

[0044] Further, by using green energy, such as solar, wind, or geothermal 25 energy, for example, as a heat source for the heating apparatus, CO<sub>2</sub> emissions may in principle be decreased to zero.

[0045] The reducing gas is then introduced into the reduction furnace through 30 a blowing process. For example, the reducing gas is introduced into the reduction furnace using a reducing gas blowing device. The iron oxide is then reduced by the reducing gas in the reduction furnace to obtain reduced iron. On the other hand, the reducing gas after being used for iron oxide reduction is discharged from the reduction furnace as the top gas.

[0046] Further, it is preferred that at least one of de-dusting or dehydration of 35 the top gas is carried out prior to the distribution process. Any deduster may be used for de-dusting. Further, any dehydrator may be used for dehydration. The order of dedusting and dehydration is not particularly limited. In the

example illustrated in FIG. 2, the top gas is dehydrated by the dehydrator after de-dusting by the deduster, and then the top gas is distributed into the first top gas and the second top gas.

5 [0047] • Control of the amount of gas introduced into distribution process, generation process, and heating process

In the method of producing reduced iron according to an embodiment of the present disclosure, it is important to control the amount of gas introduced (supplied) to the distribution process, the generation process, and the heating process, according to the CO<sub>2</sub> conversion rate. This makes it possible to 10 stabilize the composition of the reducing gas blown into the reduction furnace, particularly the ratio of the amount of H<sub>2</sub> to the amount of CO in the reducing gas, H<sub>2</sub>/CO (hereinafter also referred to as reducing gas H<sub>2</sub>/CO). This makes it possible to continue stable operations that maintain the composition of the reducing gas within a certain range without discharging CO<sub>2</sub> out of the 15 circulation system or supplying CO from outside the circulation system, and thus achieve both further energy savings and a decrease in CO<sub>2</sub> emissions under high operational stability.

20 [0048] Here, the CO<sub>2</sub> conversion rate indicates the ratio of CO<sub>2</sub> contained in the first top gas introduced into the generation process that is converted to CO by the electrolysis reaction. For example, the CO<sub>2</sub> conversion rate may be 25 calculated using the following expression.

CO<sub>2</sub> conversion rate  $\eta_c$  [-] = 1 - (amount of CO<sub>2</sub> contained in regenerative carbon monoxide gas discharged after CO generation in generation process [Nm<sup>3</sup>/t]) ÷ (amount of CO<sub>2</sub> contained in first top gas introduced into generation process [Nm<sup>3</sup>/t])

The CO<sub>2</sub> conversion rate can be adjusted mainly by the reactor itself used in the generation process. For example, the type, amount, surface area, and thickness of the materials used in the electrodes and electrolyte in the reactor, as well as the temperature of the reactor and the amount of electrical 30 power supplied to the reactor. Further, when there are other gases introduced into the generation process besides the first top gas, such as water vapor, the amount of CO<sub>2</sub> contained in such gases is also included in (amount of CO<sub>2</sub> contained in first top gas introduced into generation process [Nm<sup>3</sup>/t]).

Further, Nm<sup>3</sup>/t and kg/t are the basic units per tonne of reduced iron 35 (DRI) produced.

[0049] For example, it is suitable to control the amount of gas introduced into

the distribution process, the generation process, and the heating process to satisfy the following Expression (1).

[Math 2]

$$1 - \frac{V_{CO_2}}{W_{CO_2}} \leq \eta_C \quad \dots(1)$$

5

Here,

$W_{CO_2}$  is an amount of  $CO_2$ , in  $Nm^3/t$ , contained in the top gas introduced into the distribution process, and

$V_{CO_2}$  is an amount of  $CO_2$ , in  $Nm^3/t$ , contained in the gas introduced into the heating process.

10

$V_{CO_2}$  is the total amount of  $CO_2$  contained in the gas introduced into the heating process. The gas introduced into the heating process is essentially regenerative carbon monoxide gas and the second top gas (or mixed gas of these).

15

**[0050]** The left side of Expression (1) above can be rewritten as  $(W_{CO_2} - V_{CO_2})/W_{CO_2}$ , which represents the ratio of  $CO_2$  that is converted to  $CO$  out of the  $CO_2$  introduced into the distribution process. When Expression (1) is not satisfied, the amount of  $CO_2$  converted to  $CO$  in the generation process is not sufficient, resulting in a  $CO_2$  surplus in the circulation system. As a result, stable operation under a healthy mass balance may require the discharge of  $CO_2$  out of the circulation system.

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**[0051]** In view of the above, the amount of gas introduced into the distribution process, the generation process, and the heating process is preferably controlled to satisfy Expression (1).

25

**[0052]** The left side of Expression (1) is more preferably  $1 - V_{CO_2}/W_{CO_2} + 0.015$ . The left side of Expression (1) is even more preferably  $1 - V_{CO_2}/W_{CO_2} + 0.03$ .

30

**[0053]** The amount of gas introduced into the distribution process, the generation process, and the heating process may be constant or may be changed at any time, as long as Expression (1) is satisfied. The amount of gas to be introduced into the distribution process, the generation process, and the heating process at the time of facility startup may be determined, for example, from past operating history, and the amount of gas to be introduced into the distribution process, the generation process, and the heating process may be changed and controlled as appropriate according to subsequent operating

conditions.

**[0054]** Further, the iron oxide raw material used in the method of producing reduced iron according to an embodiment of the present disclosure is, for example, iron ore. Examples include lumped iron ore (lump ore), pellets (powdered iron ore hardened into a spherical shape), and the like. The grade of iron ore used as iron oxide raw material, that is, the iron content, is not particularly limited. From the perspective of reduction in a shaft furnace, the iron content is typically preferably 65 mass% or more.

**[0055]** In addition, the method of producing reduced iron according to an embodiment of the present disclosure describes, among other things, the use of a shaft furnace as a direct reduction iron-making process. However, the type of reduction furnace is not limited to this, and may be a fluidized bed, a rotary kiln, a rotary hearth furnace (RHF), or the like. Shaft furnaces are preferred as reduction furnaces because of their high production efficiency, ratio of utilization and operational stability. Further, the majority of direct reduction furnaces in operation worldwide are Midrex® (Midrex is a registered trademark in Japan, other countries, or both) and Hyl® (Hyl is a registered trademark in Japan, other countries, or both), which are shaft furnace systems.

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## EXAMPLES

**[0056]** Examples of the present disclosure are described below.

In the circulation system illustrated in FIG. 2, reduced iron was produced according to the conditions listed in Table 1. Under all conditions, the operation period was 28 days. In Table 1, the operating parameters are listed in terms of basic unit per tonne of reduced iron produced. For example, when 1300 kg of iron oxide pellets are used to produce 1 tonne of reduced iron, the amount of iron oxide pellets used is expressed as 1300 kg/t. When 3000 t/d of reduced iron is to be produced, this amount can be multiplied by 3000 to obtain the daily parameters.

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**[0057]** Here, under all conditions, iron oxide pellets as raw material were charged into the reduction furnace at 1394 kg/t in a charging process. In the blowing process, reducing gas heated to 980 °C was blown in from a middle portion of the reduction furnace to reduce the iron oxide pellets to obtain reduced iron. The top gas discharged from the reduction furnace was then dedusted, then dehydrated as appropriate to balance the mass balance. The top gas was then introduced into the distribution process and distributed into the

first top gas and the second top gas. In the distribution process, the top gas introduced into the top gas distributor was separated into separated carbon dioxide gas and remaining gas (CO<sub>2</sub> separation) so that the mass balance was balanced as appropriate. The separated carbon dioxide gas was then introduced 5 into the carbon monoxide generator as the first top gas, with an appropriate amount of water vapor added. Then, in the carbon monoxide generator, regenerative carbon monoxide gas was generated by a co-electrolysis reaction. After dehydrating the regenerative carbon monoxide gas as appropriate, the regenerative carbon monoxide gas was mixed with the second top gas to form 10 the mixed gas. The mixed gas was then introduced into a heating apparatus, and the mixed gas was heated in the heating apparatus to obtain the reducing gas. The total amount of introduced gas for the heating process in Table 1 is the total amount of the mixed gas, that is, the regenerative carbon monoxide gas and the second top gas. W<sub>H2</sub> is the amount of H<sub>2</sub> in the top gas introduced 15 into the distribution process. V<sub>H2</sub> is the amount of H<sub>2</sub> in the gas (regenerative carbon monoxide gas and second top gas) introduced into the heating process. Conditions other than those described above and in Table 1 were in accordance with a conventional method.

**[0058]** [Table 1]

Table 1

Parameters		Unit	Example 1	Example 2	Example 3	Example 4	Comparative Example 1	Comparative Example 2	Comparative Example 3	Comparative Example 4
Reducing gas H <sub>2</sub> /CO	-		0.14	0.36	1.49	5.65	0.14	0.36	1.49	5.65
	Introduced top gas amount	Nm <sup>3</sup> /t	1567	1653	1912	2280	1567	1653	1912	2280
W <sub>CO2</sub>	Nm <sup>3</sup> /t	655	592	399	190	655	592	399	190	
	W <sub>H2</sub>	Nm <sup>3</sup> /t	136	324	895	1516	136	324	895	1516
Total amount of introduced gas	Nm <sup>3</sup> /t	1608	1749	2176	2728	1608	1749	2176	2728	
	V <sub>CO2</sub>	Nm <sup>3</sup> /t	78	70	47	21	78	70	47	21
V <sub>H2</sub>	Nm <sup>3</sup> /t	177	420	1159	1964	177	420	1159	1964	
	CO <sub>2</sub> conversion rate $\eta_C$	-	0.95	0.9	0.93	0.94	0.86	0.87	0.84	0.87
Control of gas amount by CO <sub>2</sub> conversion rate	-	Yes	Yes	Yes	Yes	Yes	No	No	No	No
Expression (1) left-side value	-	0.88	0.88	0.88	0.89	0.88	0.88	0.88	0.88	0.89
Expression (1) satisfied?	-	Yes	Yes	Yes	Yes	Yes	No	No	No	No

[0059] For all of the Examples, the circulation system illustrated in FIG. 2, which is extremely advantageous in realizing energy savings, that is, a system in which top gas is circulated and reused, was able to operate stably under a healthy mass balance for the entire 28-day operation period. Further, CO<sub>2</sub> emissions from the circulation system could be decreased to zero.

On the other hand, for all of the Comparative Examples where the gas volume was not controlled according to the CO<sub>2</sub> conversion ratio in the generation process, the reaction in the reduction furnace became unstable during the operation period because the composition of the reducing gas could no longer be maintained within a certain range, and the operation had to be suspended.

#### REFERENCE SIGNS LIST

	[0060]	1	reduction furnace
15		1a	iron oxide
		1b	reduced iron
		3	deduster
		4	dehydrator
		5	natural gas supply
20		6	air supply
		7	reformer
		9	reducing gas blowing device
		10	water vapor supply
		11	carbon monoxide generator
25		12	heating apparatus
		13	heat source
		14	top gas distributor

## CLAIMS

[Claim 1] A method of producing reduced iron, the method comprising:  
5 a charging process of charging iron oxide into a reduction furnace;  
a blowing process of blowing reducing gas into the reduction furnace;  
a reduction process, in the reduction furnace, of reducing the iron oxide  
by the reducing gas to obtain reduced iron;  
a distribution process of distributing top gas discharged from the  
reduction furnace into a first top gas and a second top gas;  
10 a generation process of generating regenerative carbon monoxide gas  
by an electrolytic reaction using the first top gas; and  
a heating process of heating a mixed gas of the regenerative carbon  
monoxide gas and the second top gas to become the reducing gas, wherein  
an amount of gas introduced into the distribution process, the  
15 generation process, and the heating process is controlled according to a CO<sub>2</sub>  
conversion rate  $\eta_C$  from the electrolytic reaction in the generation process.

[Claim 2] The method of producing reduced iron according to claim 1,  
wherein the amount of gas introduced into the distribution process, the  
20 generation process, and the heating process is controlled so as to satisfy the  
following Expression (1),

[Math 1]

$$1 - \frac{V_{CO_2}}{W_{CO_2}} \leq \eta_C \quad \dots(1)$$

where

25 W<sub>CO<sub>2</sub></sub> is an amount of CO<sub>2</sub>, in Nm<sup>3</sup>/t, contained in the top gas  
introduced into the distribution process, and

V<sub>CO<sub>2</sub></sub> is an amount of CO<sub>2</sub>, in Nm<sup>3</sup>/t, contained in the gas introduced  
into the heating process.

30 [Claim 3] The method of producing reduced iron according to claim 1 or  
2, wherein, in the distribution process, the top gas is separated into separated  
carbon dioxide gas and remaining gas,  
the separated carbon dioxide gas is distributed as the first top gas, and  
the remaining gas is distributed as the second top gas.

## ABSTRACT

Provided is a method of producing reduced iron that can achieve both energy savings and a decrease in CO<sub>2</sub> emissions. A top gas circulation and reuse system is provided that includes a blowing process, a reduction process, a distribution process, a generation process, and a heating process. An amount of gas introduced into the distribution process, the generation process, and the heating process is controlled according to a CO<sub>2</sub> conversion rate from an electrolysis reaction in the generation process.

FIG. 1

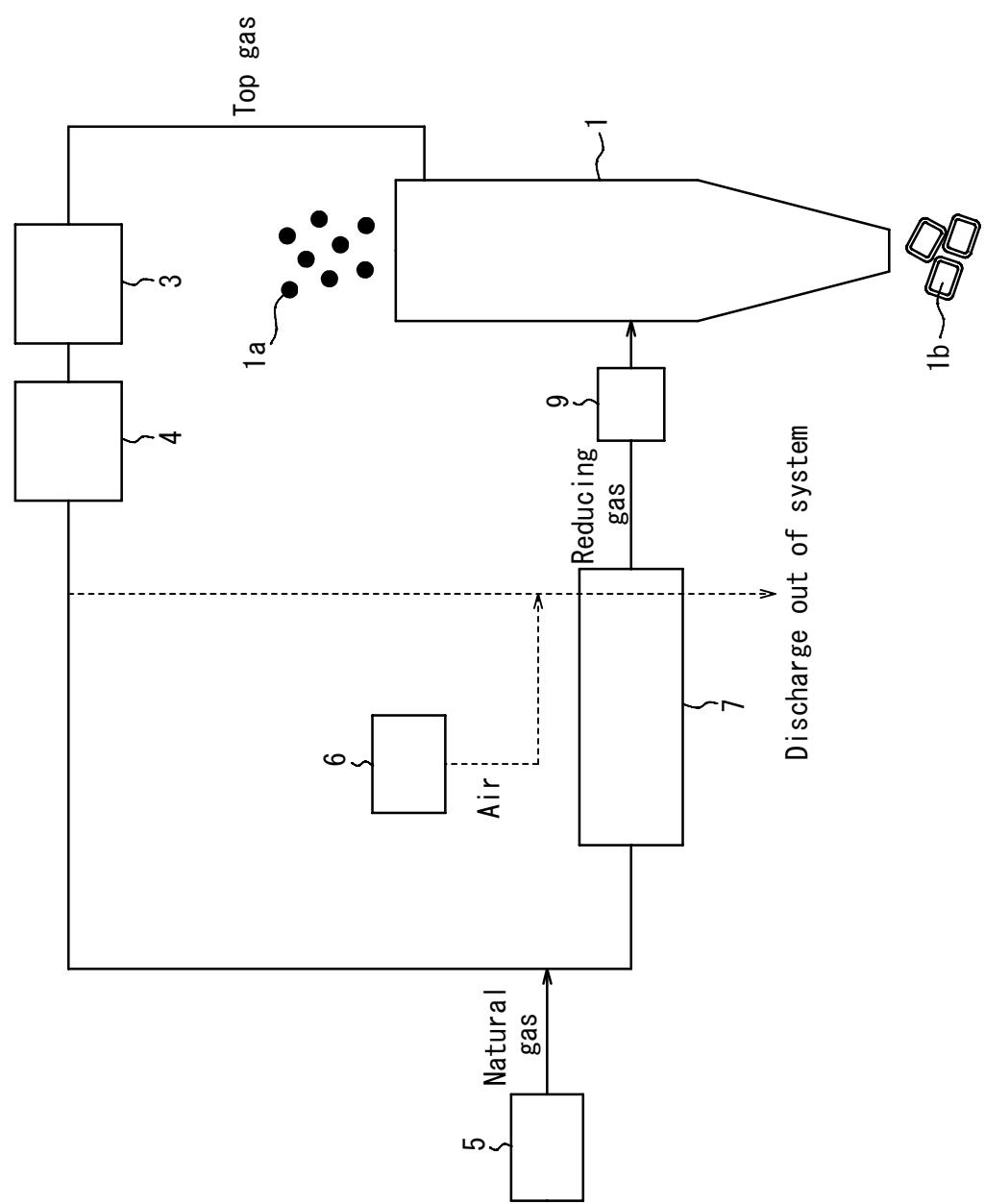


FIG. 2

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