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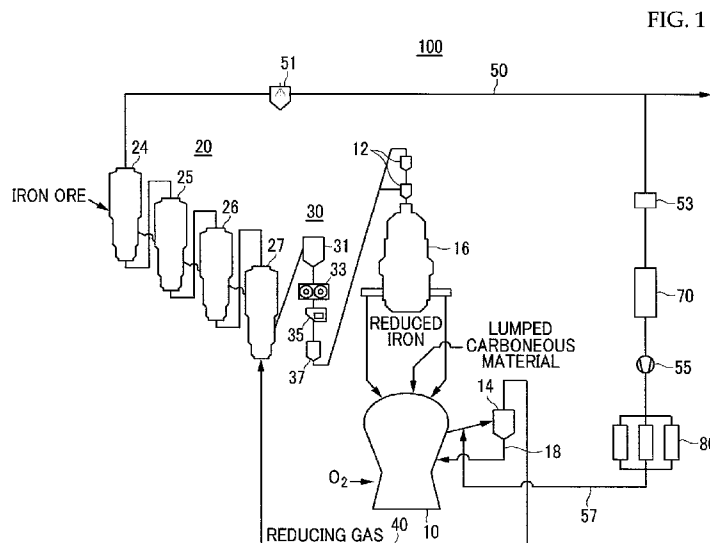
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(57) Abstract: The present invention relates to an apparatus for manufacturing molten iron and a method of manufacturing the molten iron. The apparatus for manufacturing molten iron includes at least one reduction reactor, a melter-gasifier, an offgas supply line, and at least one reformer. The at least one reduction reactor reduces iron ore to form reduced iron. The melter-gasifier is connected to the reduction reactor. The reduced iron, a lumped carbonaceous material, and oxygen are provided to the melter-gasifier to form molten iron. The offgas supply line circulates an offgas discharged from the reduction reactor to the reduction reactor. The at least one reformer is installed at the offgas supply line to raise the amount of hydrogen included in the offgas.

WO 2009/082123 A2

APPARATUS FOR MANUFACTURING MOLTEN IRON AND METHOD FOR MANUFACTURING THE SAME

Technical Field

5 This application claims priority to and the benefit of Korean Patent Application No. 2007-0137303 filed on December 26, 2007 in the Korean Intellectual Property Office, the entire content of which is incorporated herein by reference.

10 The present invention relates to an apparatus for manufacturing molten iron and a method of manufacturing the molten iron. More particularly, the present invention relates to an apparatus for manufacturing molten iron that is capable of improving a reduction rate of a reducing gas and a method of manufacturing the molten iron.

Background Art

15 Recently, a smelting reduction method that is capable of replacing the conventional blast furnace method has been developed. In the smelting reduction method, raw coal is directly used as a fuel and a reducing agent. In addition, iron ore is directly used as an iron source. The iron ore is reduced in the reduction reactor and molten iron is formed in the melter-gasifier.

20 Oxygen is injected into the melter-gasifier so that a coal-packed bed in the melter-gasifier may be burned. The oxygen is transformed into a reducing gas to be discharged from the melter-gasifier, and is then transferred to the reduction reactor. The iron ore is reduced by the reducing gas in the reduction reactor, and the reducing gas is then discharged from the
25 reduction reactor as an offgas.

DISCLOSURE

Technical Problem

30 The present invention provides an apparatus for manufacturing molten iron that is capable of improving a reduction ratio of a reducing gas. In addition, the present invention provides a method of manufacturing molten iron that is capable of improving a reduction ratio of a reducing gas.

Technical Solution

An apparatus for manufacturing molten iron according to an embodiment of the present invention includes at least one reduction reactor, a melter-gasifier, an offgas supply line and at least one reformer. The at least
5 one reduction reactor reduces an iron ore to form a reduced iron. The melter-gasifier is connected to the reduction reactor. The reduced iron, a lumped carbonaceous material, and oxygen are provided to the melter-gasifier to form molten iron. The offgas supply line circulates an offgas discharged from the reduction reactor to the reduction reactor. The at least one reformer is
10 installed at the offgas supply line to raise the amount of hydrogen included in the offgas.

The at least one reformer may include a water gas shift reactor (WGSR) or a pressure swing absorber (PSA). The at least one reformer includes a plurality of reformers, the plurality of reformers including the
15 WGSR and the PSA.

The apparatus for manufacturing molten iron further includes a gas compressor installed at the offgas supply line to compress the offgas. The gas compressor is located at a front portion of the WGSR or an end portion of the WGSR along with the WGSR. The WGSR causes a chemical reaction of the
20 carbon monoxide in the offgas to produce hydrogen, and the PSA absorbs carbon dioxide in the offgas. The amount of the hydrogen passing through the WGSR ranges from about 38vol% to about 100vol% with respect to the offgas.

The PSA extracts hydrogen from the offgas and discharges the
25 hydrogen. The amount of hydrogen discharged from the PSA ranges from about 97vol% to about 100vol% with respect to the offgas. The apparatus for manufacturing molten iron further includes a vapor injector connected to the reduction reactor to inject a vapor into the reduction reactor.

The reduction reactor may be a packed-bed reactor or a fluidized-bed
30 reduction reactor. The at least one reduction reactor includes a plurality of fluidized bed reactors in a case in which the reduction reactor is the fluidized-bed reduction reactor. The plurality of fluidized bed reactors

include a first fluidized bed reactor preheating the iron ore, a second fluidized bed reactor connected to the first fluidized bed reactor to pre-reduce the preheated iron ore, and a third fluidized bed reactor connected to the second fluidized bed reactor to finally reduce the pre-reduced iron ore.

5 The apparatus for manufacturing molten iron further includes a vapor injector located between the first fluidized bed reactor and the second fluidized bed reactor to inject a vapor into the first fluidized bed reactor.

The apparatus for manufacturing molten iron further includes a reducing gas supply line providing a reducing gas discharged from the melter-gasifier into the reduction reactor. The reducing gas supply line is connected to the offgas supply line. The offgas supply line is installed at the melter-gasifier to supply the offgas into the melter-gasifier through a tuyere that injects the oxygen. The offgas is circulated to the reduction reactor through the melter-gasifier.

10

A method of manufacturing molten iron according to an embodiment of the present invention includes forming reduced iron by charging the iron ore into the reduction reactor, charging a lumped carbonaceous material into a melter-gasifier, charging the reduced iron into the melter-gasifier, forming the molten iron by charging oxygen into the melter-gasifier to melt the reduced iron, raising the amount of hydrogen in the offgas by reforming the offgas, and providing the reformed offgas to the reduction reactor. The offgas is reformed by using at least one reformer installed at an offgas supply line connected with the reduction reactor to provide the offgas discharged from the reduction reactor

15 20

The at least one reformer is a WGSR or a PSA in raising the amount of hydrogen. The at least one reformer includes a plurality of reformers. The plurality of reformers includes a WGSR and a PSA.

25

The method of manufacturing the molten iron further includes compressing the offgas by using a gas compressor installed at the offgas supply line. The gas compressor is located at a front portion or an end portion of the WGSR along with the WGSR in compressing the offgas. The amount of hydrogen in the offgas is increased after compressing the offgas.

30

The WGSR causes a chemical reaction of the carbon monoxide in the offgas to produce hydrogen, and the PSA absorbs carbon dioxide included in the offgas. The amount of hydrogen passing through the WGSR is about 38vol% to about 100vol% with respect to the amount of the offgas. The PSA
5 extracts hydrogen from the offgas and discharges the hydrogen, and the amount of hydrogen discharged from the PSA is about 97vol% to about 100vol% with respect to the amount of the offgas. The method of manufacturing the molten iron may further include injecting a vapor into the reduction reactor.

10 The forming of the molten iron includes preheating the iron ore, pre-reducing the preheated iron ore, and finally reducing the pre-reduced iron ore. The vapor may be used to preheat the iron ore. The reduction reactor is a packed-bed reactor or a fluidized-bed reduction reactor in forming the reduced iron.

15 The method of manufacturing the molten iron may further include providing a reducing gas generated from the melter-gasifier into the reduction reactor. The reformed offgas is mixed with the reducing gas to be provided to the reduction reactor in providing the reformed offgas into the reduction reactor. The oxygen is provided to the melter-gasifier through a
20 tuyere installed at the melter-gasifier in forming the molten iron. The reformed offgas may be provided to the melter-gasifier through the tuyere in providing the reformed offgas to the reduction reactor, and the reformed offgas is provided to the reduction reactor through the melter-gasifier.

Advantageous Effects

25 A reducing gas is reformed using a WGSR and a PSA so that a reduction ratio of the reducing gas may be significantly improved. In addition, the reducing gas has a largely increased amount of hydrogen so that a melting point of the iron ore may be largely decreased. Thus, a cost of fuel required for manufacturing the molten iron may be largely saved.

DESCRIPTION OF DRAWINGS

FIG. 1 schematically illustrates an apparatus for manufacturing

molten iron in accordance with a first embodiment of the present invention.

FIG. 2 illustrates a reduction ratio of iron ore according to a composition of a reducing gas.

FIG. 3 schematically illustrates an apparatus for manufacturing
5 molten iron in accordance with a second embodiment of the present invention.

FIG. 4 schematically illustrates an apparatus for manufacturing molten iron in accordance with a third embodiment of the present invention.

FIG. 5 schematically illustrates an apparatus for manufacturing
10 molten iron in accordance with a fourth embodiment of the present invention.

FIG. 6 schematically illustrates an apparatus for manufacturing molten iron in accordance with a fifth embodiment of the present invention.

FIG. 7 schematically illustrates an apparatus for manufacturing molten iron in accordance with a sixth embodiment of the present invention.

FIG. 8 schematically illustrates an apparatus for manufacturing
15 molten iron in accordance with a seventh embodiment of the present invention.

FIG. 9 schematically illustrates an apparatus for manufacturing molten iron in accordance with an eighth embodiment of the present
20 invention.

FIG. 10 schematically illustrates an apparatus for manufacturing molten iron in accordance with a ninth embodiment of the present invention.

FIG. 11 schematically illustrates an apparatus for manufacturing molten iron in accordance with tenth embodiment of the present invention.

FIG. 12 schematically illustrates an apparatus for manufacturing
25 molten iron in accordance with an eleventh embodiment of the present invention.

FIG. 13 and FIG. 14 sequentially illustrate variations of iron ores according to Example 1 and Comparative Example 1, respectively.

FIG. 15 illustrates variations of components in an offgas according to
30 Example 2.

FIG. 16 illustrates variations of components in an offgas according to

Example 3.

BEST MODE

The invention will be described more fully hereinafter with reference
5 to the accompanying drawings, in which embodiments of the invention are
shown. This invention may, however, be embodied in many different forms
and should not be construed as limited to the embodiments set forth herein.
Rather, these embodiments are provided so that this disclosure will be
thorough and complete, and will fully convey the scope of the invention to
10 those skilled in the art. Like reference numerals refer to like elements
throughout.

All terms including technical and scientific terms used herein have
the same meaning as commonly understood by one of ordinary skill in the
art to which this invention belongs. It will be further understood that terms,
15 such as those defined in commonly used dictionaries, should be interpreted
as having a meaning that is consistent with their meaning in the context of
the relevant art and the present disclosure, and will not be interpreted in an
idealized or overly formal sense unless expressly so defined herein.

FIG. 1 schematically illustrates an apparatus for manufacturing
20 molten iron 100 in accordance with a first embodiment of the present
invention.

Referring to FIG. 1, the apparatus for manufacturing molten iron 100
includes a plurality of fluidized-bed reduction reactor 20, a melter-gasifier 10,
a reducing gas supply line 40, and reformers 70 and 80. In addition, the
25 apparatus for manufacturing molten iron 100 may further include a device
for forming compacted iron 30, a hot pressure equalizing device 12, and a
compacted iron storage unit 16.

The apparatus for manufacturing molten iron 100 may manufacture
the molten iron 100 by using iron ore and coal. The iron ore is provided into
30 the fluidized-bed reduction reactor 20 to fluidize the iron core in the
fluidized-bed reduction reactor 20. A fine iron ore may be employed as the
iron ore, and an additional material may be added into the iron ore. A
fluidized bed is formed in the fluidized-bed reduction reactor 20 to reduce
the iron ore, and the fluidized-bed reduction reactor 20 includes a first
35 fluidized bed reactor 24, a second fluidized bed reactor 25, a third fluidized

bed reactor 26, and a fourth fluidized bed reactor 27. Although four fluidized bed reactors are illustrated in FIG. 1, at least one fluidized bed reactor may be used. In addition, although the fluidized bed reactor is illustrated in FIG. 1, this is merely to illustrate the present invention and the present invention is not limited thereto. Thus, another reducing reactor may be used.

The first fluidized bed reactor 24 may preheat the iron ore by using a reducing gas exhausted from the second fluidized bed reactor 25. The second fluidized bed reactor 25 and the third fluidized bed reactor may pre-reduce the preheated iron ore, and the fourth fluidized bed reactor 27 may finally reduce the pre-reduced iron ore to form reduced iron.

The iron ore may be heated and reduced when passing through the fluidized-bed reduction reactor 20. The reducing gas produced and exhausted from the melter-gasifier 10 is supplied to the fluidized-bed reduction reactor 20 through the reducing gas supply line 40, and a cyclone 14 is installed to prevent fine iron dust included in the reducing gas exhausted from the melter-gasifier from being scattered. Thus, the fine iron dust is collected by the cyclone 14 and then provided into the melter-gasifier 10 again. The iron ore is reduced by the reducing gas in the fluidized-bed reduction reactor 20 to form the reduced iron, and the reduced iron is formed into compacted iron by a device for forming the compacted iron 30.

The device for forming the compacted iron 30 includes a charging hopper 31, a pair of rollers 33, a crusher 35, and a storage unit 37. In addition, the device for forming the compacted iron 30 may further include another unit. The charging hopper 31 may store the reduced iron, the reduced iron is charged from the charging hopper 31 into the pair of rollers 33 to be pressed and molded into a strip-shaped form, and the pressed and molded reduced iron is crushed by the crusher 35 and then stored in the storage unit 37.

The reduced iron stored in the storage unit 37 is transferred to the melter-gasifier 10. The hot pressure equalizing device 12 may control a pressure between the device for forming the compacted iron 30 and the melter-gasifier 10 to transfer the compacted iron to the melter-gasifier 10 by force. The compacted iron storage unit 16 may temporarily store the compacted iron and charge the compacted iron to the melter-gasifier 10.

Lumped carbonaceous materials may be charged into the melter-gasifier 10 to form a coal-packed bed at an inside thereof. Examples of the

lumped carbonaceous material may be lump coal or coal briquettes. The coal briquettes may be formed by pressing and molding fine iron dust coal. In addition, coke may be charged thereto. Oxygen (O₂) may be provided to the melter-gasifier 10. The oxygen (O₂) is provided in the coal-packed bed to
5 form a raceway. The lumped carbonaceous material is burned at the raceway to produce the reducing gas, the compacted iron is melted by burning the lumped carbonaceous materials to form the molten iron, and the molten iron is then discharged to the outside.

Fine iron dust is included in the offgas exhausted through an offgas
10 line 50 from the first fluidized bed reactor 24. Thus, as illustrated in FIG. 1, the fine iron dust is collected by water provided from a water scrubber 51 installed at the offgas line 50. The offgas may be selectively exhausted through the offgas line 50. The fine iron dust collected by water forms a sludge. The sludge is then exhausted to the outside.

15 A portion of the offgas is exhausted to the outside. The remaining offgas is provided to a tar removing device 53 so that tar included in the offgas may be removed. Thus, a problem due to condensation of the tar at the reformers 70 and 80 and the gas compressor 56 located around an end portion of the tar removing device 53 may be prevented.

20 The reformers 70 and 80 may reform the offgas to extract a predetermined gas. The reformers 70 and 80 may be pressure swing absorbers (PSA) or water gas shift reactors (WGSR). As illustrated in FIG. 1, the WGSR 70 and the PSA 80 may be used as the reformers.

The PSA includes a plurality of absorbers having fine and long pipes
25 wherein a plurality of fine holes is formed. The absorbers serve as filters, and they may be carbon molecular sieves (CMS) or zeolite molecular sieves (ZMS). A difference in absorbance degree between gases included the offgas may occur according to sizes of the fine holes when the offgas passes through the absorber. That is, a certain gas is absorbed in the absorber, but another
30 gas may pass through the absorber without being absorbed. Pressure of the PSA is lowered after the offgas passes through PSA completely so that the gas absorbed in the absorber may be removed from the PSA.

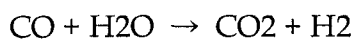
The size of the fine holes that are capable of absorbing the offgas may be varied in accordance with the kind of the offgas. In addition, variation of
35 the fine holes may be well known to persons skilled in the art. Thus, further

explanation will be omitted.

The WGSR may produce a predetermined gas from the offgas. When the WGSR is installed at a front portion of the PSA, the WGSR may function properly. That is, when the predetermined gas is extracted by the PSA after it
5 is produced by the WGSR, an extracted amount and purity of the predetermined gas may increase.

For example, the WGSR may add moisture to carbon monoxide included in the offgas by using a catalyst so that a chemical reaction of the carbon monoxide and the moisture may produce hydrogen. This reaction
10 may occur at a temperature of about 200°C to about 450°C. This reaction may be represented by Chemical Formula 1 as follows:

【Chemical Formula 1】



15

On the basis of Chemical Formula 1, a chemical reaction between the moisture and the carbon monoxide may occur in the WGSR so that the hydrogen and the carbon dioxide may be generated.

The above-described structure and operation principle of the WGSR
20 are well known to persons skilled in the art. Thus, further explanation will be omitted.

As illustrated in FIG. 1, the tar removing device 50, the WGSR 70, the gas compressor 55, and the PSA 80 are installed at the offgas supply line 57 separated from the offgas line 50. The WGSR 70 is located at an end portion
25 of the PSA 80, and the gas compressor 55 is located between the WGSR 70 and the PSA 80. The gas compressor 55 may increase the pressure of the offgas. The offgas having the increased pressure is provided to the PSA 80 located at an end portion of the gas compressor 55. A pressure of a gas provided to the gas compressor 55 may be increased so that the PSA 80 may
30 operate effectively.

The WGSR 70 may add moisture to the offgas to form carbon dioxide and hydrogen. The WGSR 70 is located around an end portion of the tar removing device 53 to receive the offgas from which the tar is removed.

The PSA 80 may remove carbon dioxide. That is, carbon dioxide
35 included in the offgas passing through the PSA 80 is absorbed and removed

by the absorber of the PSA 80 and the rest of the offgas may pass through the PSA 80. The carbon dioxide removed from the PSA 80 may be used in an electric power station or an iron works. The carbon dioxide may be used in the electric power station or the iron works for fire extinguishing.

5 When the offgas passes through the WGSR 70 and the PSA 80, the composition ratio of the offgas may be changed. Carbon monoxide, carbon dioxide, hydrogen, nitrogen, etc., are included in the offgas before the offgas passes through the WGSR 70 and the PSA 80. A large amount of carbon monoxide may be reacted with the moisture to be changed into carbon
10 dioxide and hydrogen while the offgas passes through the WGSR 70. The carbon dioxide may be removed while the offgas including the increased amounts of carbon dioxide and hydrogen passes through the PSA 80. Thus, the amount of hydrogen included in the offgas may increase.

 The offgas passing through the PSA 80 may be circulated to the
15 fluidized-bed reduction reactor 20 through the offgas supply line 57. Here, the reformed offgas may be mixed with the reducing gas produced from the melter-gasifier 10 and then provided to the fluidized-bed reduction reactor 20. The offgas supply line 57 may be connected to a line connected the melter-gasifier 10 and the cyclone 14, so the reformed offgas may be
20 exhausted from the cyclone 14 and provided to the fluidized-bed reduction reactor 20 through the reducing gas supply line 40. In addition, the cyclone 14 may collect fine iron dust and then provide it to the melter-gasifier 10 again through a line 18. Thus, the hydrogen included in the offgas may be provided to the fluidized-bed reduction reactor 20 through the reducing gas
25 supply line 40. Hereinafter, as illustrated in the first embodiment of the present invention, an affect of the amount of the hydrogen in the reducing gas with respect to a reduction ratio of the iron ore will be explained.

 FIG. 2 illustrates the reduction ratio of the iron ore according to the amount of hydrogen included in the reducing gas in the fluidized-bed
30 reduction reactor. Line A in FIG. 2 indicates a case where the amount of hydrogen in the reducing gas is about 100 vol%, line B in FIG. 2 indicates a case where the amounts of hydrogen and carbon monoxide in the reducing gas are about 50vol% and about 50vol%, respectively, and line C indicates a case where the amount of the carbon monoxide in the reducing gas is about
35 100vol%.

The reduction ratios of the iron ore at a temperature of about 700°C, about 800°C, and about 900°C are indicated in lines A, B, and C by using a rhombus, a quadrangle, and a triangle, respectively. Here, the temperature is an inner temperature of the fluidized-bed reduction reactor.

5 Referring to line A, when the inner temperatures of the fluidized-bed reduction reactor are about 700°C, about 800°C, and about 900°C, the reduction ratios of the iron ore are about 75%, about 88%, and about 90%, respectively. In addition, referring to line B, when the inner temperatures of the fluidized-bed reduction reactor are about 700°C, about 800°C, and about
10 900°C, the reduction ratios of the iron ore are about 61%, about 79%, and about 80%, respectively. Referring to line C, when the temperatures of the melter-gasifier are about 700°C, about 800°C, and about 900°C, the reduction ratios of the iron ore are about 35%, about 43%, and about 52%, respectively.

Referring to FIG. 2, the reduction ratio of the iron ore increases when
15 the inner temperature of the fluidized-bed reduction reactor increases. However, when the inner temperature of the fluidized-bed reduction reactor increases, the iron ore may be attached to the inside of the fluidized-bed reduction reactor so that fluidity may decrease. Thus, it is required to properly control the inner temperature of the fluidized-bed reduction reactor.

20 As illustrated in FIG. 2, when the amount of the hydrogen in the reducing gas increases, the reduction ratio of the iron ore may increase. Referring to line C, when the reducing gas having 100vol% carbon monoxide is used, the iron ore reduction ratio may be about 52% when the inner temperature of the fluidized-bed reduction reactor is about 900°C. On the
25 other hand, in line A, when the reducing gas having 100vol% carbon monoxide is used, the iron ore reduction ratio may be about 75% when the inner temperature of the fluidized-bed reduction reactor is about 700°C. That is, when the amount of the hydrogen in the reducing gas increases, the inner temperature of the fluidized-bed reduction reactor may decrease and the
30 reduction ratio of the iron ore may increase.

Thus, the offgas is reformed to increase the amount of hydrogen and the offgas is used as the reducing gas. Thus, energy efficiency of the apparatus for manufacturing molten iron may increase. In addition, the cost required for manufacturing the molten iron may decrease.

35 FIG. 3 schematically illustrates an apparatus for manufacturing

molten iron 200 in accordance with a second embodiment of the present invention. The apparatus for manufacturing molten iron 200 in FIG. 3 is substantially the same as the apparatus for manufacturing molten iron 100 in FIG. 1. Thus, the same reference numerals will be used to refer to the same or like parts as those described in FIG. 1, and further explanation will be omitted.

As illustrated in FIG. 3, the gas compressor 55 is located at a front portion of the WGSR 70. The gas compressor 55 may increase the pressure of the offgas, and the WGSR 70 may produce hydrogen from the offgas. When the compressed offgas is provided to the WGSR 70, the reaction speed between carbon monoxide and moisture may increase. That is, the WGSR 70 may use the compressed offgas to effectively produce the hydrogen and the carbon dioxide. The PSA 80 may remove carbon dioxide to provide the offgas having the increased amount of hydrogen to the melter-gasifier 10.

FIG. 4 schematically illustrates an apparatus for manufacturing molten iron in accordance with a third embodiment of the present invention. The apparatus for manufacturing molten iron 300 is substantially the same as the apparatus for manufacturing molten iron 100 in FIG. 1. Thus, the same reference numerals will be used to refer to the same or like parts as those described in FIG. 1, and further explanation will be omitted.

As illustrated in FIG. 4, a vapor injector 90 is located between a first fluidized bed reactor 24 and a second fluidized bed reactor 25. Although the vapor injector 90 is located between the first fluidized bed reactor 24 and the second fluidized bed reactor 25 in FIG. 4, this is merely to illustrate the present invention and the present invention is not limited thereto. Thus, the vapor injector 90 may be located at another position. The vapor injector 90 may inject a vapor to the fluidized-bed reduction reactor 20. The vapor injector 90 is located between the first fluidized bed reactor 24 and the second fluidized bed reactor 25 to increase the reducing gas preheating the iron ore charged into the first fluidized bed reactor 24. Thus, preheat efficiency of the iron ore may increase.

While reducing the iron ore, a portion of the iron ore exists in a form of an iron oxide (Fe_3O_4). Thus, when the vapor is injected from the vapor injector 90, the iron oxide serves as a catalyst so that the vapor and the carbon monoxide in the reducing gas may be reacted with each other. Thus,

the amounts of hydrogen and carbon dioxide in the reducing gas may be increased by the above-described Chemical Formula 1. This is substantially similar to a case where the iron oxide (Fe_3O_4) is used as a catalyst in the WGSR 70 in FIG. 1. The WGSR produces the hydrogen and the carbon dioxide by using the iron oxide (Fe_3O_4) catalyst.

As illustrated in FIG. 4, a portion of hydrogen increased by the vapor injector 90 may preheat or pre-reduce the iron ore in the first fluidized bed reactor 24. The rest of the hydrogen may be exhausted through the offgas line 50. Thus, the amount of hydrogen in the offgas may increase. The amount of carbon dioxide in the offgas is also high, like the hydrogen included in the offgas. The carbon dioxide is removed when passing through the PSA 80. That is, the amount of hydrogen included in the offgas may be increased without use of the WGSR in accordance with the third embodiment. Thus, the cost for fuel may be saved when the apparatus for manufacturing molten iron 300 is used.

FIG. 5 schematically illustrates an apparatus for manufacturing molten iron 400 in accordance with a fourth embodiment of the present invention. The apparatus for manufacturing molten iron 400 in FIG. 1 is substantially the same as the apparatus for manufacturing molten iron 100 in FIG. 1. Thus, the same reference numerals will be used to refer to the same or like parts as those described in FIG. 1, and further explanation will be omitted.

The amounts of carbon dioxide and hydrogen in the offgas may increase while the offgas passes through the WGSR 70, and the offgas having the increased amount of hydrogen is provided to the PSA 81. The PSA 81 may discharge hydrogen selectively. Thus, carbon monoxide, carbon dioxide, and nitrogen included in the offgas may be removed by the PSA 81. The hydrogen may be selectively provided to the melter-gasifier 10 by the PSA 81, so the amount of hydrogen included in the reducing gas may be largely increased such that a reduction rate of the iron ore may increase.

When the carbon dioxide is absorbed and removed by the PSA, the nitrogen may not be absorbed. The nitrogen may not be used as the reducing gas. The nitrogen may dilute the reducing gas so that the reduction ratio of the iron ore may be decreased. When the nitrogen is absorbed by using the PSA, carbon monoxide having substantially the same absorptive degree as

nitrogen may also be absorbed. Thus, it is impossible to separate the nitrogen included in the reducing gas. However, in accordance with the fourth embodiment of the present invention, the amount of hydrogen in the offgas may increase and the amount of carbon monoxide may decrease while the
5 offgas passes through the WGSR 70. Thus, the carbon monoxide and the nitrogen may be simultaneously removed by using the PSA 81.

FIG. 6 schematically illustrates an apparatus for manufacturing molten iron 500 in accordance with a fifth embodiment of the present invention. The apparatus for manufacturing molten iron 500 in FIG. 6 is
10 substantially the same as the apparatus for manufacturing molten iron 400 in FIG. 5. Thus, the same reference numerals will be used to refer to the same or like parts as those described in FIG. 5, and further explanation will be omitted.

As illustrated in FIG. 6, the gas compressor 55 may be located at a
15 front portion of the WGSR 70. The gas compressor 55 may increase the pressure of the offgas, and the offgas is reformed in the WGSR 70. Thus, the reaction speed between carbon monoxide and moisture may be increased by providing the compressed offgas to the WGSR 70. Therefore, the WGSR 70 may produce the hydrogen and the carbon dioxide more effectively.

While the offgas passes through the PSA 81, the offgas may be
20 separated into hydrogen and a component except for the hydrogen. The hydrogen is discharged from the PSA 81 and then provided to the melter-gasifier 10, and the component except for the hydrogen may be removed. Thus, the amount of hydrogen in the reducing gas may be largely increased
25 so that a reduction ratio of the iron ore may be increased.

FIG. 7 schematically illustrates an apparatus for manufacturing molten iron 600 in accordance with a sixth embodiment of the present invention. The apparatus for manufacturing molten iron 600 is substantially
30 the same as the apparatus for manufacturing molten iron 100 in FIG. 1. Thus, the same reference numerals will be used to refer to the same or like parts as those described in FIG. 1, and further explanation will be omitted. In addition, the vapor injector 90 is substantially the same as the vapor injector 90 in FIG. 4, so the same reference numerals will be used to refer to the same or like parts and further explanation will be omitted.

35 As illustrated in FIG. 7, the iron oxide may be used as the catalyst by

the vapor injector 90 so that the injected vapor and the carbon monoxide in the reducing gas may be reacted with each other. The amounts of hydrogen and carbon dioxide in the reducing gas may therefore increase, and the increased hydrogen passes through the first fluidized bed reactor 24 to be discharged from the offgas line 50. When the offgas passes through the WGSR 70, the amounts of the hydrogen and the carbon dioxide in the offgas may increase. That is, the hydrogen may be produced twice when passing through the vapor injector 90 and the WGSR 70, so the amount of hydrogen in the offgas may increase. Here, the carbon dioxide may be absorbed and removed by the PSA 80 so that the amount of hydrogen gas in the offgas provided to the melter-gasifier 10 may be relatively large.

FIG. 8 schematically illustrates an apparatus for manufacturing molten iron 700 in accordance with a seventh embodiment of the present invention. The apparatus for manufacturing molten iron 700 in FIG. 8 is substantially the same as the apparatus for manufacturing molten iron 200 in FIG. 3. Thus, the same reference numerals will be used to refer to the same or like parts as those described in FIG. 3, and further explanation will be omitted. In addition, the vapor injector 90 is substantially the same as the vapor injector 90 in FIG. 4, so the same reference numerals will be used to refer to the same or like parts and further explanation will be omitted.

As illustrated in FIG. 8, the amounts of hydrogen and carbon dioxide in the reducing gas may be increased by the vapor injector 90. The reducing gas passes through the first fluidized bed reactor 24, and is then discharged as the offgas through the offgas line 50. The pressure of the offgas may be increased when the offgas passes through the gas compressor 55, and when the compressed offgas is provided to the WGSR 70, the hydrogen and the carbon dioxide may be effectively produced. The hydrogen may be produced twice when passing through the vapor injector 90 and the WGSR 70 so that the amount of the hydrogen in the offgas may be increased. Here, the carbon dioxide may be absorbed and removed by the PSA 80 so that the amount of hydrogen in the offgas provided to the melter-gasifier 10 may be relatively large.

FIG. 9 schematically illustrates an apparatus for manufacturing molten iron 800 in accordance with an eighth embodiment of the present invention. The apparatus for manufacturing molten iron 800 in FIG. 9 is

substantially the same as the apparatus for manufacturing molten iron 400 in FIG. 5. Thus, the same reference numerals will be used to refer to the same or like parts as those described in FIG. 5, and further explanation will be omitted. In addition, the vapor injector 90 is substantially the same as the vapor injector 90 in FIG. 4, so the same reference numerals will be used to refer to the same or like parts and further explanation will be omitted

As illustrated in FIG. 9, the amounts of hydrogen and carbon dioxide in the reducing gas may be increased by the vapor injector 90. The reducing gas passes through the first fluidized bed reactor 24 and the reducing gas is then discharged as the offgas through the offgas line 50. The hydrogen may be produced twice when passing through the vapor injector 90 and the WGSR 70 so that the amount of hydrogen may be increased. When the offgas passes through the PSA 81, the hydrogen may be selectively provided through the offgas supply line 57, and the remaining components may be removed. The PSA 81 may provide the melter-gasifier 10 with the hydrogen and remove the carbon monoxide, carbon dioxide, nitrogen, etc. Thus, the amount of hydrogen in the reducing gas may be largely increased so that the reduction ratio of the iron ore may be largely increased.

FIG. 10 schematically illustrates an apparatus for manufacturing molten iron 900 in accordance with a ninth embodiment of the present invention. The apparatus for manufacturing molten iron 900 in FIG. 10 is substantially the same as the apparatus for manufacturing molten iron 500 in FIG. 6. Thus, the same reference numerals will be used to refer to the same or like parts as those described in FIG. 6, and further explanation will be omitted. In addition, the vapor injector 90 in FIG. 4 is substantially the same as the vapor injector 90 in FIG. 4, so the same reference numerals will be used to refer to the same or like parts and further explanation will be omitted.

As illustrated in FIG. 10, the amounts of hydrogen and carbon dioxide in the reducing gas may be increased by the vapor injector 90. The reducing gas may pass through the first fluidized bed reactor 24 and the reducing gas may be discharged as the offgas passes through the offgas line 50. The offgas may be compressed when passing through the gas compressor 55, and it is provided to the WGSR 70 so that it may be reformed. Thus, the hydrogen and the carbon dioxide may be effectively produced. That is, the hydrogen may be produced twice when passing through the vapor injector

90 and the WGSR 70 so that the amount of hydrogen in the offgas may increase.

The offgas passes through the PSA 81 so that components in the offgas except for hydrogen may be removed. Thus, the PSA 81 may
5 selectively provide the melter-gasifier 10 with hydrogen. The PSA 81 may remove carbon monoxide, carbon dioxide, nitrogen, etc. As a result, the amount of hydrogen in the reducing gas may be largely increased so that the reduction ratio of the iron ore may be increased.

FIG. 11 schematically illustrates an apparatus for manufacturing
10 molten iron 1000 in accordance with a tenth embodiment of the present invention. The apparatus for manufacturing molten iron 1000 in FIG. 11 is substantially the same as the apparatus for manufacturing molten iron 100 in FIG. 1. Thus, the same reference numerals will be used to refer to the same or like parts as those described in FIG. 1, and further explanation will be
15 omitted.

As illustrated in FIG. 11, the reducing gas that is reformed by passing through the WGSR 70 and the PSA 81 may be directly provided to the melter-gasifier 10. That is, the reducing gas together with oxygen may be directly provided to the melter-gasifier 10 through a tuyere (not shown)
20 installed at the melter-gasifier 10. Thus, the offgas may be provided to the fluidized-bed reduction reactor 20 through the melter-gasifier 10. In this case, the melting point of the iron ore melted in the melter-gasifier 10 may largely decrease. That is, the reducing gas that is reformed to have the increased amount of hydrogen is used so that the melting point of the iron ore may
25 largely decrease. As a result, the cost of fuel required for manufacturing the molten iron may be substantially reduced.

FIG. 12 schematically illustrates an apparatus for manufacturing molten iron 1100 in accordance with an eleventh embodiment of the present invention. The apparatus for manufacturing molten iron 1100 in FIG. 12 is
30 substantially the same as the apparatus for manufacturing molten iron 100 in FIG. 1. Thus, the same reference numerals will be used to refer to the same or like parts as those described in FIG. 1, and further explanation will be omitted.

As illustrated in FIG. 12, the apparatus for manufacturing molten iron
35 1100 includes a packed-bed reactor 22. Although not particularly illustrated

in FIG. 12, the apparatus for manufacturing molten iron may include both the packed-bed reactor and the fluidized-bed reduction reactor. In addition, the apparatus for manufacturing molten iron may include a plurality of packed-bed reactors. The iron ore is charged into the packed-bed reactor 22, the reducing gas produced from the melter-gasifier 10 is supplied to the packed-bed reactor 22 through the reducing gas supply line 40, and the iron ore may be reduced by the reducing gas in the packed-bed reactor 22. Thus, the iron ore may be changed into reduced iron. The reduced iron is charged into the melter-gasifier 10, and the reduced iron is then melted by the coal-packed bed formed by the lumped carbonaceous material. The molten iron may be formed by the above-described method.

The offgas discharged from the packed-bed reactor 22 may pass through the WGSR 70 and the PSA 80. The amounts of hydrogen and carbon dioxide may be increased while the offgas passes through the WGSR 70. When the offgas passes through the PSA 80, the carbon dioxide in the offgas may be removed. Thus, the amount of hydrogen in the offgas provided to the packed-bed reactor 22 may be relatively large. As a result, the reduction ratio of the iron ore in the packed-bed reactor 22 may be largely increased.

In addition, although not particularly illustrated in FIG. 12, the reformed offgas may be directly provided to the melter-gasifier 10. In this case, the melting point of the iron ore may largely decrease. Thus, the cost of fuel required for manufacturing the molten iron may be substantially reduced.

Hereinafter, the present invention is more fully described with reference to examples. The examples are provided so that this disclosure will be thorough and complete, but the invention should not be construed as limited to the examples set forth herein.

Example 1

Iron ore was charged into a chamber having the same conditions as the melter-gasifier in FIG. 11. A reduction gas was provided to the chamber and variations of melting point of the iron ore according to an increase in temperature of the chamber were measured four times. Variation of shape of the iron ore was also measured. The reducing gas included 33vol% of hydrogen and 67vol% of carbon monoxide.

Results of Example 1

FIG. 13 sequentially illustrates variations of the iron ore according to Example 1.

As illustrated in FIG. 13, the temperature of the chamber increases such that the temperatures of the chamber subsequently become about 1300°C, about 1400°C, about 1430°C, and about 1440°C. Thus, the iron ore was melted. When the temperature of the chamber was about 1300°C, the variation of the shape of the iron ore did not occur. When the temperature of the chamber was about 1400°C, the iron ore was slightly melted. When the temperature of the chamber was about 1430°C, most of the iron ore was melted. When the temperature of the chamber was about 1440°C, the iron ore was completely melted. Thus, it was verified that the melting point of the iron ore according to Example 1 was about 1400°C.

Comparative Example 1

Iron ore was charged into a chamber having the same conditions as the melter-gasifier in FIG. 11. A reduction gas was provided to the chamber, and variations of melting point of the iron ore according to an increase in a temperature of the chamber were measured four times. A variation of shape of the iron ore was also measured. The reducing gas included 100vol% of carbon monoxide.

Results of Comparative Example 1

FIG. 14 sequentially illustrates variations of the iron ore according to Comparative Example 1.

As illustrated in FIG. 14, the temperature of the chamber increases such that the temperatures of the chamber subsequently become about 1300°C, about 1400°C, about 1490°C, and about 1500°C. Thus, the iron ore was melted. When the temperature of the chamber was about 1300°C and about 1400°C, the variation of the shape of the iron ore did not occur. When the temperature of the chamber was about 1490°C, the iron ore was melted from the inside of the iron ore. When the temperature of the chamber was about 1500°C, most of the iron ore was melted. Thus, it was verified that the melting point of the iron ore according to Comparative Example 1 was about 1500°C.

When comparing Example 1 with Comparative Example 1, the melting point of Example 1 was lower than Comparative Example 1 by about 90°C. That is, when the reducing gas including 100vol% of carbon monoxide

was used, the melting point was relatively low in comparison to the case where the reducing gas including hydrogen was used. Thus, the melting point of the iron ore may be lowered by increasing the amount of hydrogen in the reducing gas. As a result, a cost of fuel required for manufacturing the molten iron may be reduced.

Example 2

Components in the offgas measured before the offgas passed through the WGSR in FIG. 1 and components in the offgas measured after the offgas passes through the WGSR were inspected.

Results of Example 2

FIG. 15 illustrates variations of components in the offgas before and after passing through the WGSR.

As illustrated in FIG. 15, the offgas having a flow rate of about 1.0 L/min included 20vol% nitrogen, 30vol% carbon dioxide, 20vol% hydrogen, and 30vol% carbon monoxide. The total flow rate of the offgas passing through the WGSR was increased to about 1.25 L/min, and the offgas included 16vol% nitrogen, 45vol% carbon dioxide, 38vol% hydrogen, and 0.5vol% carbon monoxide. That is, the flow rates of carbon dioxide and hydrogen in the offgas and reduction ratios of carbon dioxide and hydrogen in the reduction gas increased. On the other hand, flow rates of carbon monoxide in the offgas and a reduction ratio of carbon monoxide in the reduction gas decreased. The amount of nitrogen in the reducing gas decreased to about 16vol%. However, the flow rate of nitrogen was not varied before and after passing the WGSR.

As described above, when the offgas passes through the WGSR, the flow rate and the amount of hydrogen and carbon dioxide in the offgas increased, and the flow rate and the amount of carbon monoxide decreased. Thus, the amount of hydrogen in the offgas was raised by using the WGSR.

Example 3

Components in the offgas measured before the offgas passed through the PSA in FIG. 5 and components in the offgas measured after the offgas passes through the WGSR were inspected.

Result of Example 3

FIG. 16 illustrates variations of components in the offgas before and after passing through the PAS. Here, the PSA selectively discharged

hydrogen in the offgas, and the remaining components in the offgas were removed.

As illustrated in FIG. 16, the offgas included 16vol% nitrogen, 45vol% carbon dioxide, 38vol% hydrogen, and 0.5vol% carbon monoxide. The amounts of carbon dioxide and hydrogen in the offgas were relatively high.
5 On the other hand, the offgas included 3vol% nitrogen and 97vol% hydrogen, so the amount of hydrogen in the offgas may be maximized by using the PSA.

The foregoing is illustrative of the present invention and is not to be construed as limiting thereof. Although a few embodiments of this invention
10 have been described, those skilled in the art will readily appreciate that many modifications are possible in the embodiments without materially departing from the novel teachings and advantages of this invention. Accordingly, all such modifications are intended to be included within the scope of this invention as defined in the claims. Therefore, it is to be understood that the
15 foregoing is illustrative of the present invention and is not to be construed as limited to the specific embodiments disclosed, and that modifications to the disclosed embodiments, as well as other embodiments, are intended to be included within the scope of the appended claims. The invention is defined by the following claims, with equivalents of the claims to be included therein.

WHAT IS CALIMED IS:

1. An apparatus for manufacturing molten iron, comprising:
at least one reduction reactor reducing iron ore to form reduced iron;
5 a melter-gasifier connected to the reduction reactor, the reduced iron,
a lumped carbonaceous material, and oxygen being provided to the melter-
gasifier to form molten iron;
an offgas supply line circulating an offgas discharged from the
reduction reactor to the reduction reactor; and
10 at least one reformer installed at the offgas supply line to raise the
amount of hydrogen included in the offgas.
2. The apparatus of Claim 1, wherein the at least one reformer
includes a water gas shift reactor (WGSR) or a pressure swing absorber (PSA).
15
3. The apparatus of Claim 2, wherein the at least one reformer
includes a plurality of reformers, the plurality of reformers including the
WGSR and the PSA.
- 20 4. The apparatus of Claim 3, further including a gas compressor
installed at the offgas supply line to compress the offgas, the gas compressor
being located at a front portion of the WGSR or an end portion of the WGSR
along with the WGSR.
- 25 5. The apparatus of Claim 3, wherein the WGSR causes a
chemical reaction of the carbon monoxide in the offgas to produce hydrogen,
and the PSA absorbs carbon dioxide in the offgas.
6. The apparatus of Claim 5, wherein the amount of hydrogen
30 passing through the WGSR ranges from about 38vol% to about 100vol% with
respect to the offgas.
7. The apparatus of Claim 3, wherein the PSA extracts hydrogen
from the offgas and discharges the hydrogen.

35

8. The apparatus of Claim 7, wherein the amount of hydrogen discharged from the PSA ranges from about 97vol% to about 100vol% with respect to the offgas.

5 9. The apparatus of Claim 2, further comprising a vapor injector connected to the reduction reactor to inject a vapor into the reduction reactor.

10 10. The apparatus of Claim 1, wherein the reduction reactor is a packed-bed reactor or a fluidized-bed reduction reactor.

11. The apparatus of Claim 1, wherein the at least one reduction reactor includes the plurality of fluidized bed reactors when the reduction reactor is the fluidized-bed reduction reactor,

15 wherein the plurality of fluidized bed reactors include a first fluidized bed reactor preheating the iron ore, a second fluidized bed reactor connected to the first fluidized bed reactor to pre-reduce the preheated iron ore, and a third fluidized bed reactor connected to the second fluidized bed reactor to finally reduce the pre-reduced iron ore, and

20 wherein the apparatus for manufacturing molten iron further comprises a vapor injector located between the first fluidized bed reactor and the second fluidized bed reactor to inject a vapor into the first fluidized bed reactor.

25 12. The apparatus of Claim 1, further comprising a reducing gas supply line providing a reducing gas discharged from the melter-gasifier into the reduction reactor,

wherein the reducing gas supply line is connected to the offgas supply line.

30 13. The apparatus of Claim 1, wherein the offgas supply line is installed at the melter-gasifier to supply the offgas into the melter-gasifier through a tuyere that injects the oxygen,

wherein the offgas is circulated to the reduction reactor through the melter-gasifier.

35

14. A method of manufacturing molten iron, the method comprising:
forming reduced iron by charging iron ore into the reduction reactor;
charging a lumped carbonaceous material into a melter-gasifier,
5 charging the reduced iron into the melter-gasifier;
forming molten iron by charging oxygen into the melter-gasifier to melt the reduced iron;
raising the amount of hydrogen in the offgas by reforming the offgas, the offgas being reformed by using at least one reformer installed at an offgas
10 supply line connected with the reduction reactor to provide the offgas discharged from the reduction reactor; and
providing the reformed offgas to the reduction reactor.
15. The method of Claim 14, wherein the at least one reformer is a
15 WGSR or a PSA in raising the amount of hydrogen.
16. The method of Claim 15, wherein the at least one reformer includes a plurality of reformers, the plurality of reformers including a
20 WGSR and a PSA.
17. The method of Claim 16, further comprising compressing the offgas by using a gas compressor installed at the offgas supply line,
wherein the gas compressor is located at a front portion or an end
25 portion of the WGSR along with the WGSR in compressing the offgas.
18. The method of Claim 17, wherein the amount of hydrogen in the offgas is increased after compressing the offgas.
19. The method of Claim 16, wherein the WGSR causes a
30 chemical reaction of the carbon monoxide in the offgas to produce hydrogen, and the PSA absorbs carbon dioxide included in the offgas.
20. The method of Claim 19, wherein the amount of hydrogen
35 passing through the WGSR is about 38vol% to about 100vol% with respect to the amount of the offgas.

21. The method of Claim 16, wherein the PSA extracts hydrogen from the offgas and discharges the hydrogen.
- 5 22. The method of Claim 21, wherein the amount of hydrogen discharged from the PSA is about 97vol% to about 100vol% with respect to the amount of the offgas.
- 10 23. The method of Claim 14, further comprising injecting a vapor into the reduction reactor.
24. The method of Claim 23, wherein the forming of the molten iron includes:
preheating the iron ore;
15 pre-reducing the preheated iron ore; and
finally reducing the pre-reduced iron ore,
wherein the vapor is used to preheat the iron ore.
- 20 25. The method of Claim 14, wherein the reduction reactor is a packed-bed reactor or a fluidized-bed reduction reactor in forming the reduced iron.
26. The method of Claim 14, further comprising providing a reducing gas generated from the melter-gasifier into the reduction reactor,
25 wherein the reformed offgas is mixed with the reducing gas to be provided to the reduction reactor in providing the reformed offgas into the reduction reactor.
- 30 27. The method of Claim 14, wherein the oxygen is provided to the melter-gasifier through a tuyere installed at the melter-gasifier in forming the molten iron,
wherein the reformed offgas is provided to the melter-gasifier through the tuyere in providing the reformed offgas to the reduction reactor,
and
35 wherein the reformed offgas is provided to the reduction reactor

through the melter-gasifier.

FIG. 1

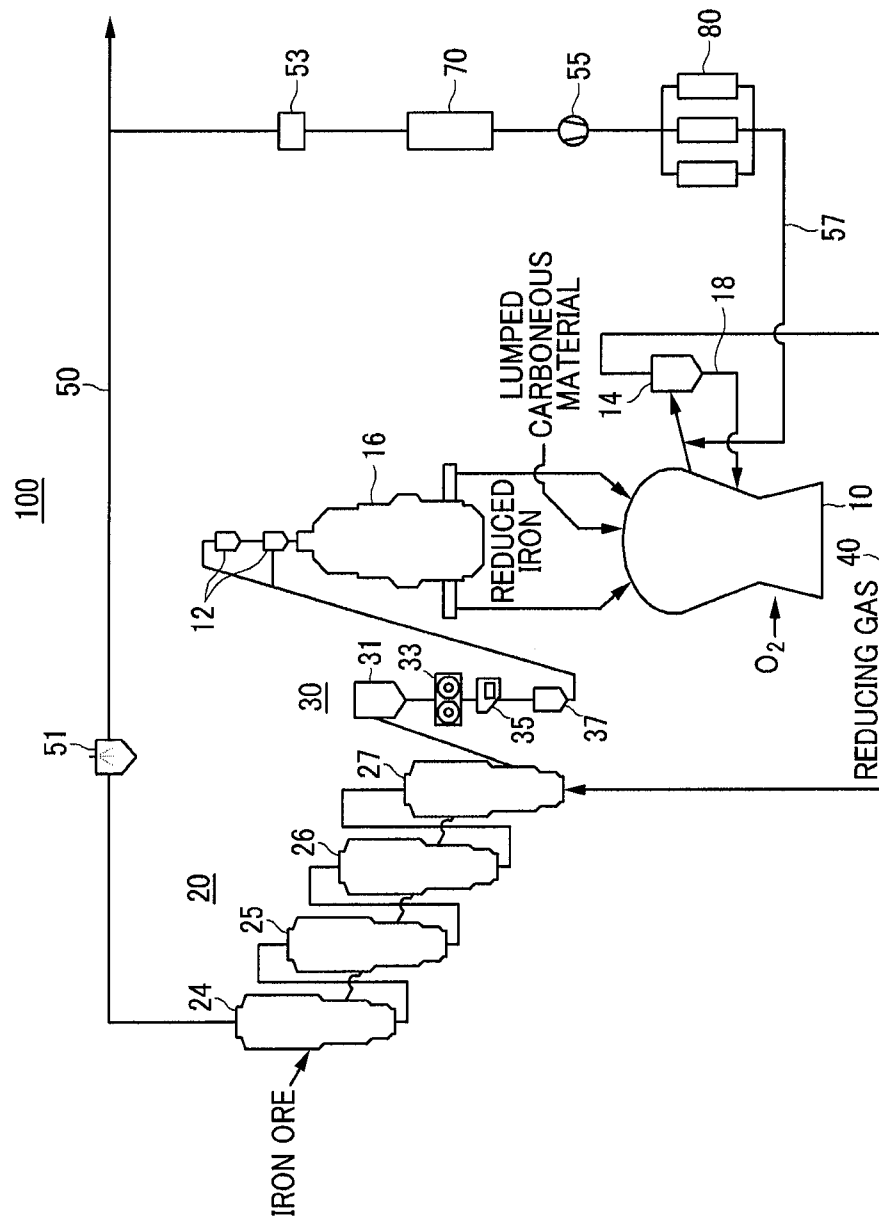


FIG. 2

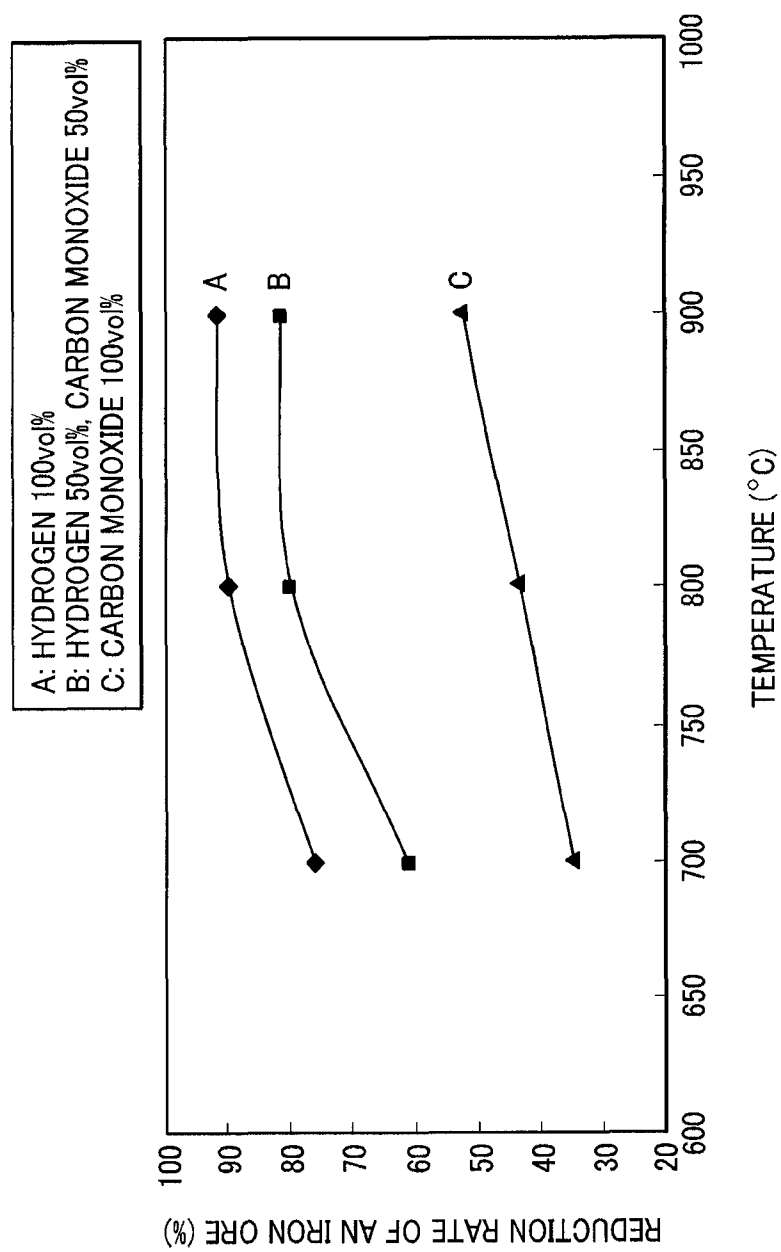


FIG. 3

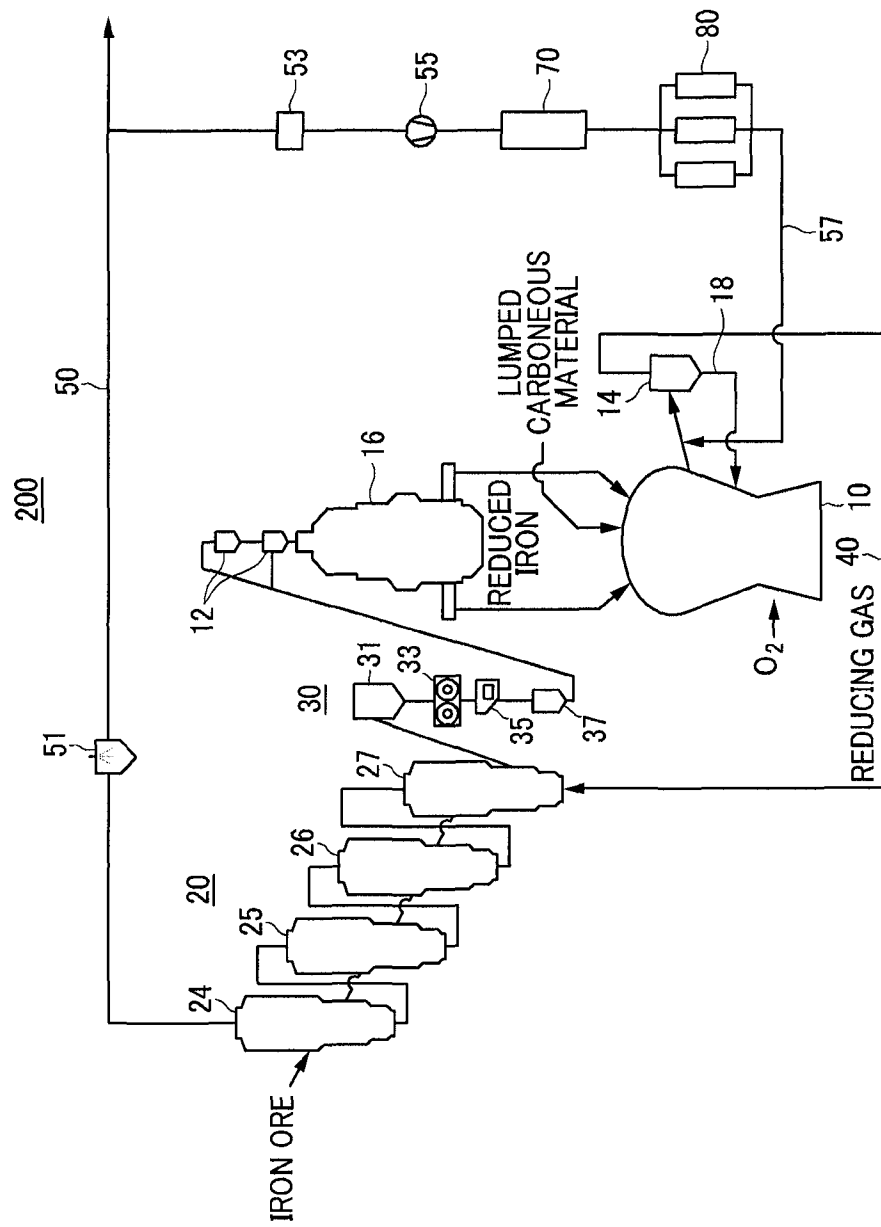


FIG. 4

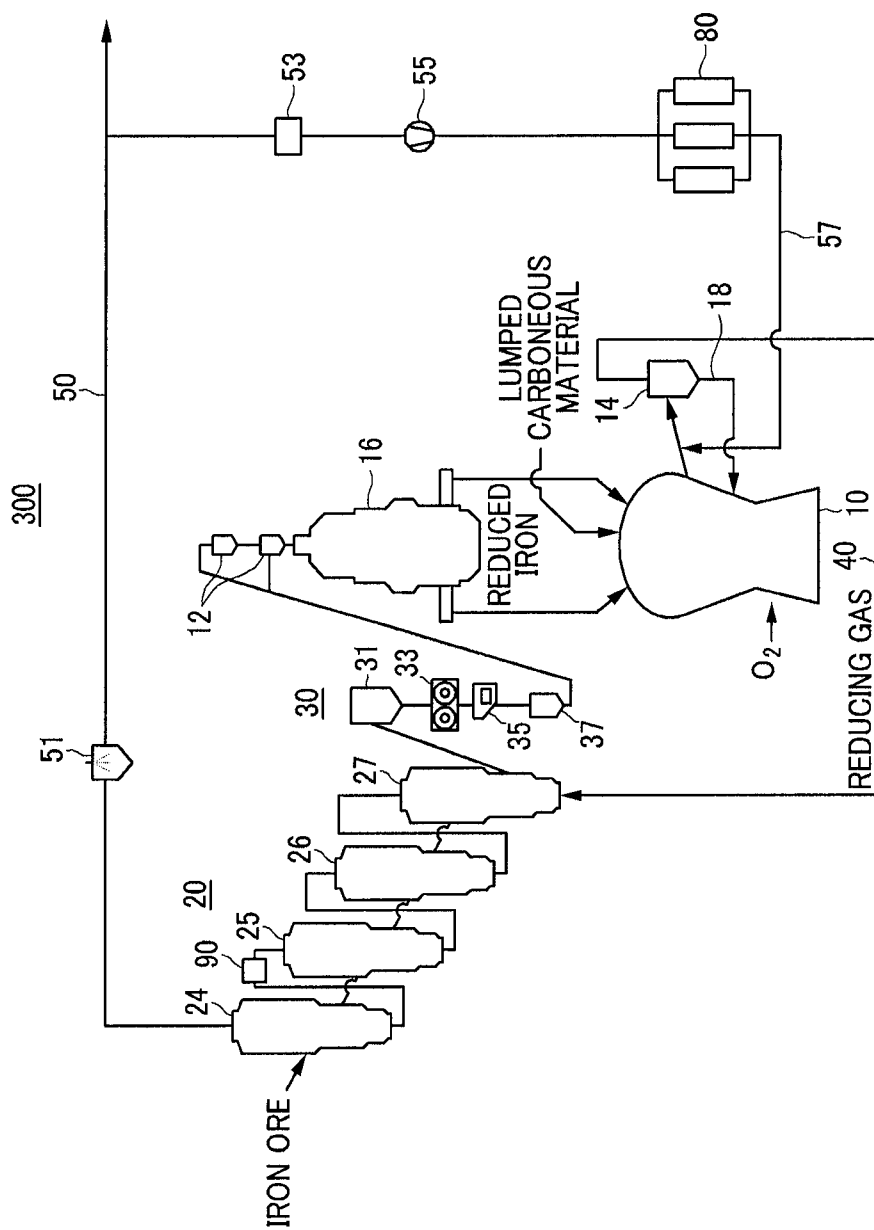


FIG. 5

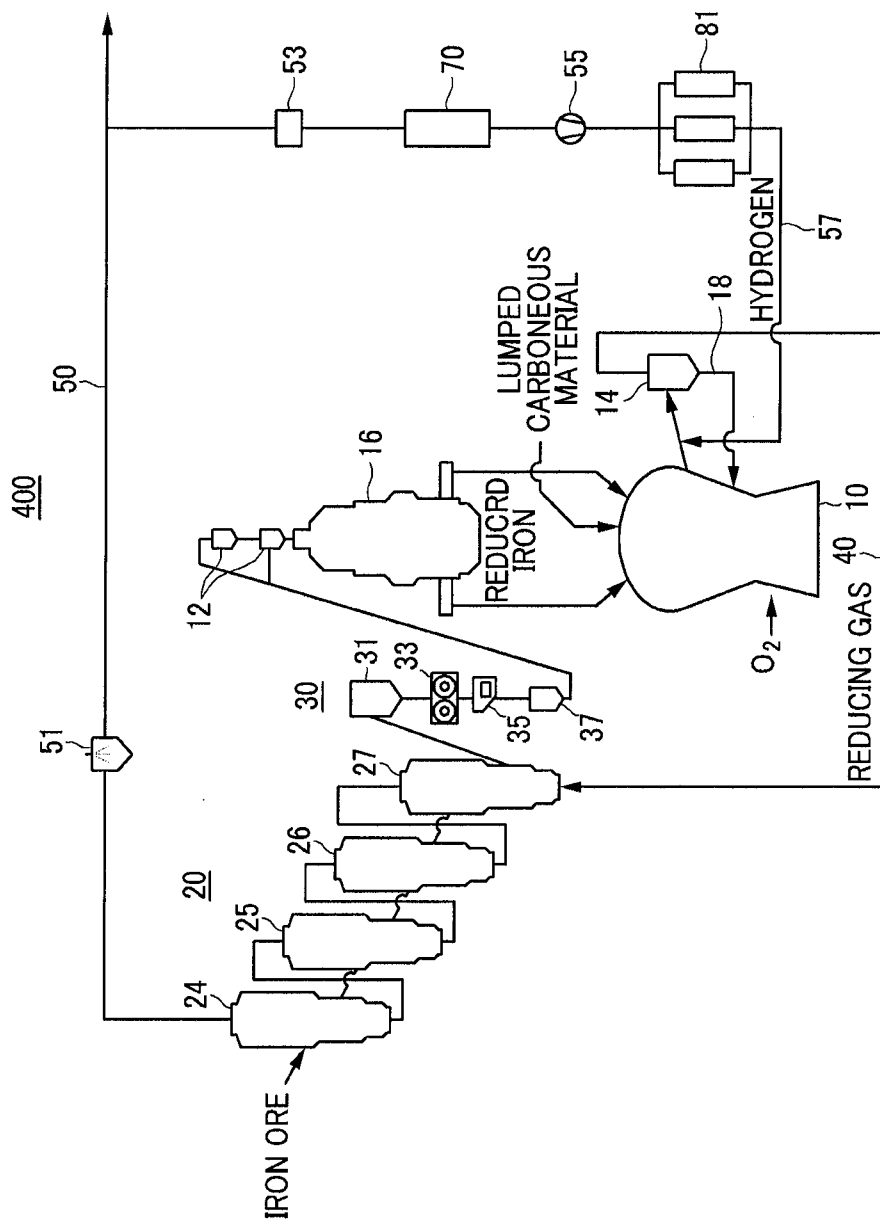


FIG. 6

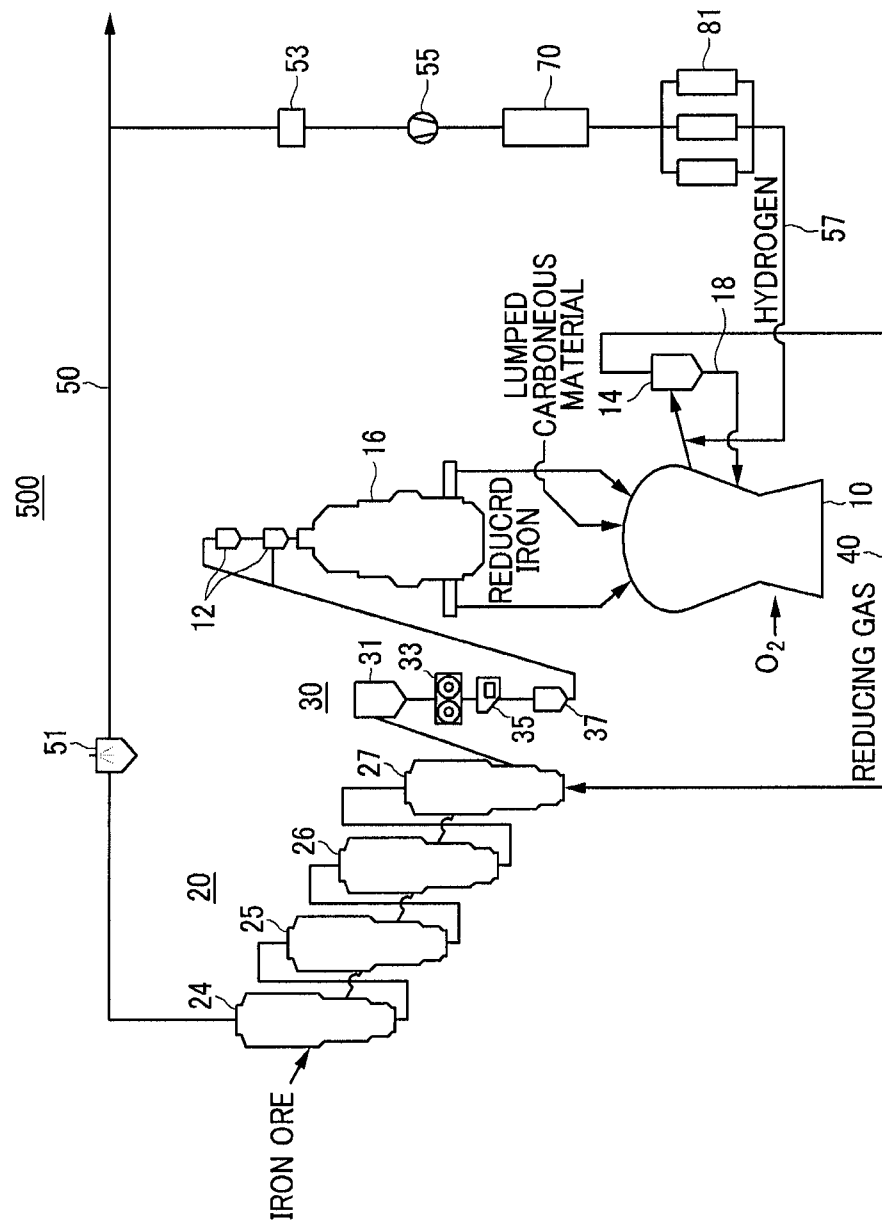


FIG. 7

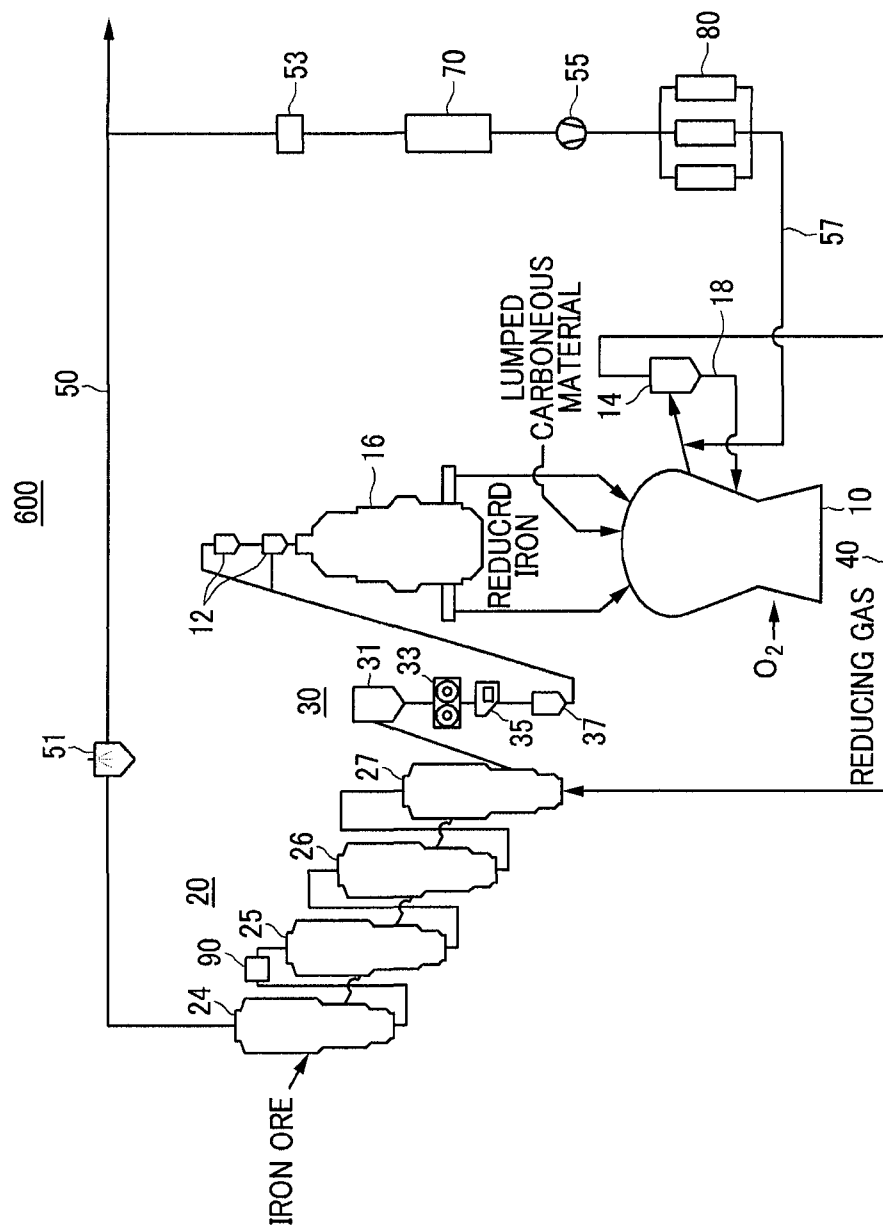


FIG. 8

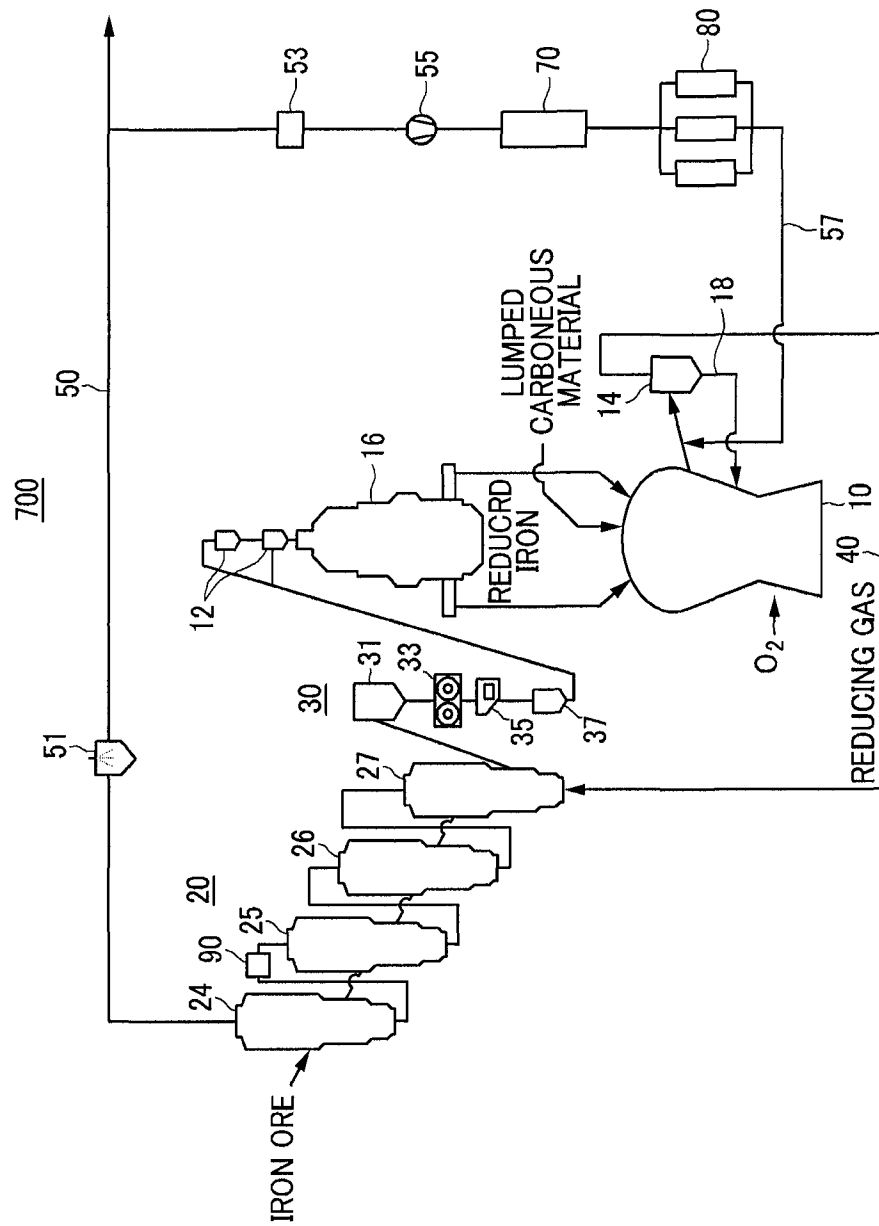


FIG. 9

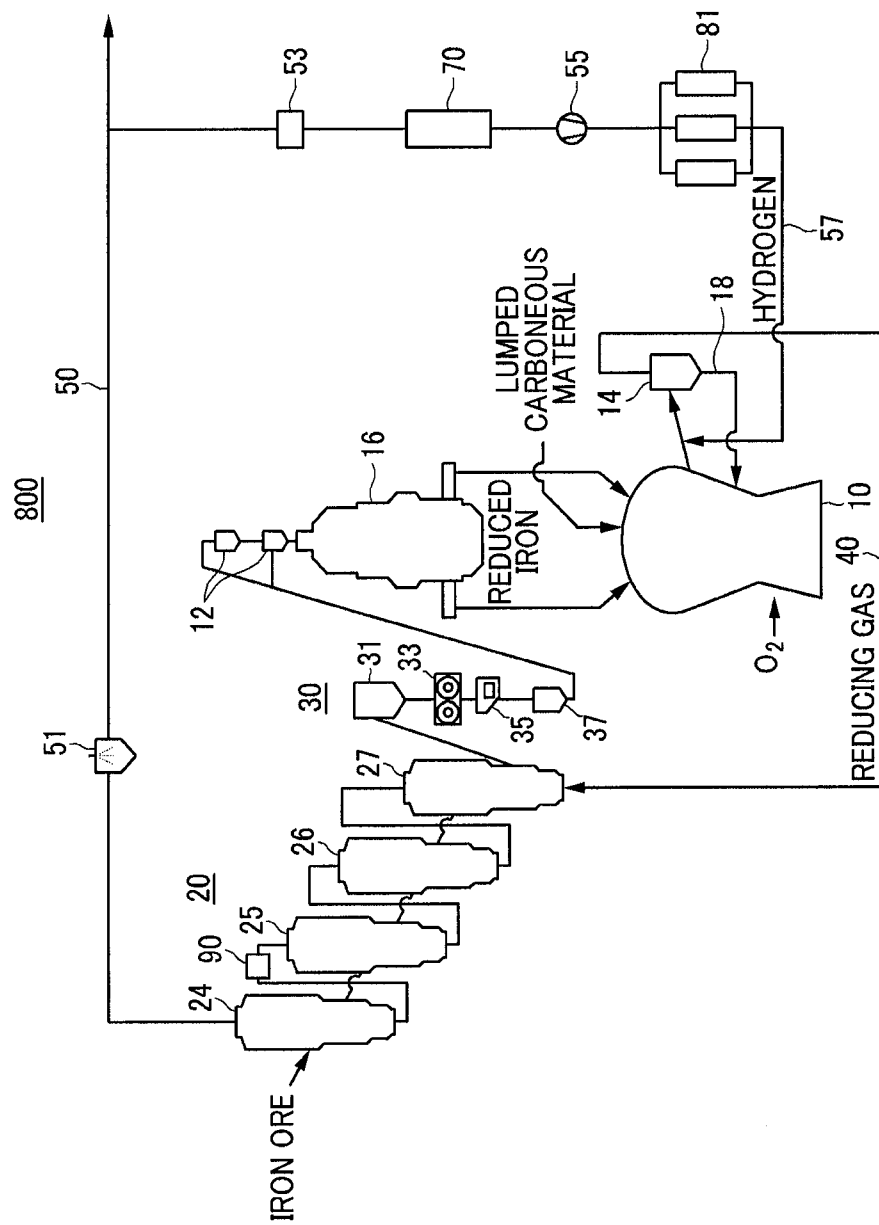


FIG. 10

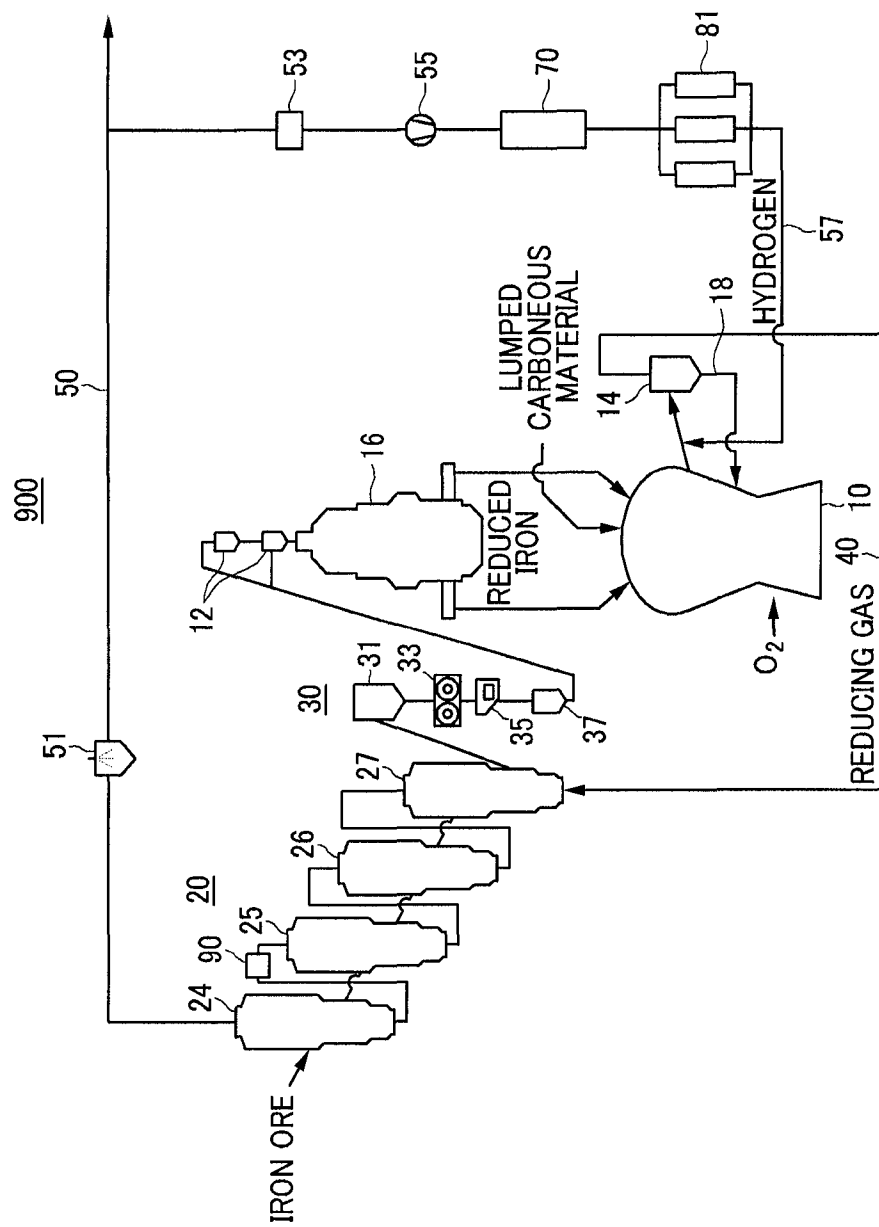


FIG. 11

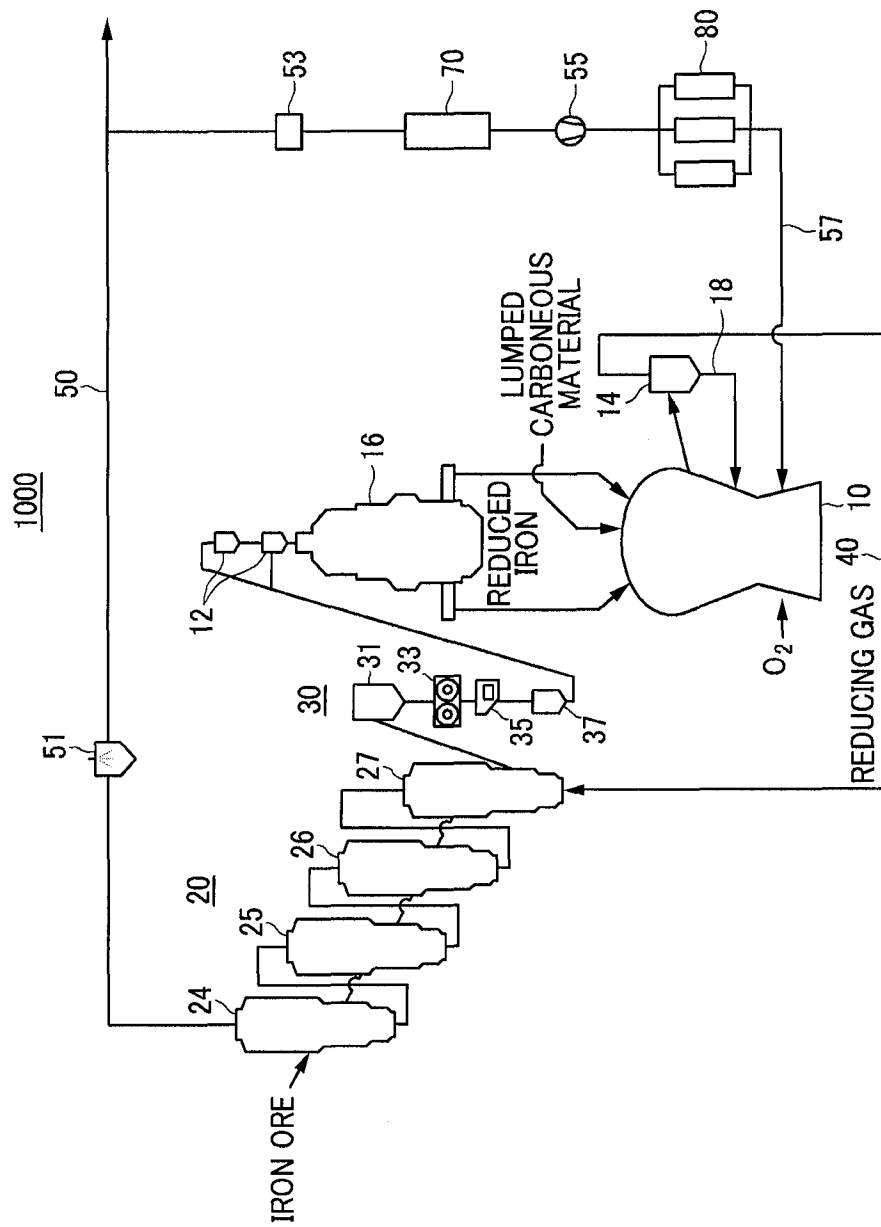


FIG. 12

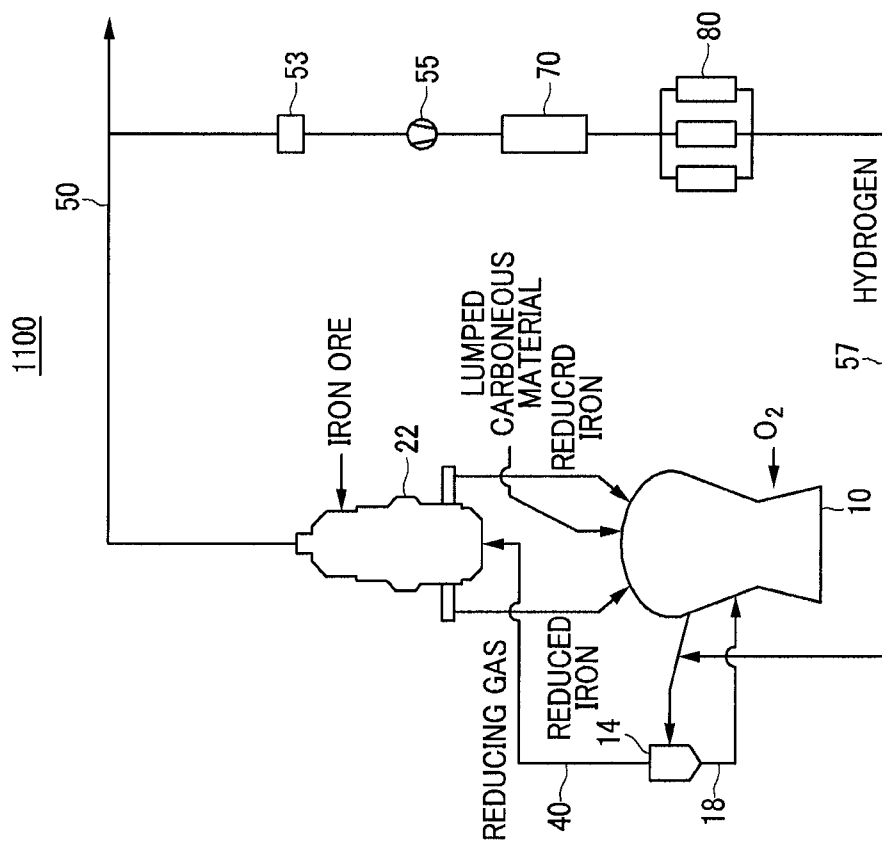


FIG. 13

Reduction and smelting (33% H₂ + 67% CO gas)



FIG. 14

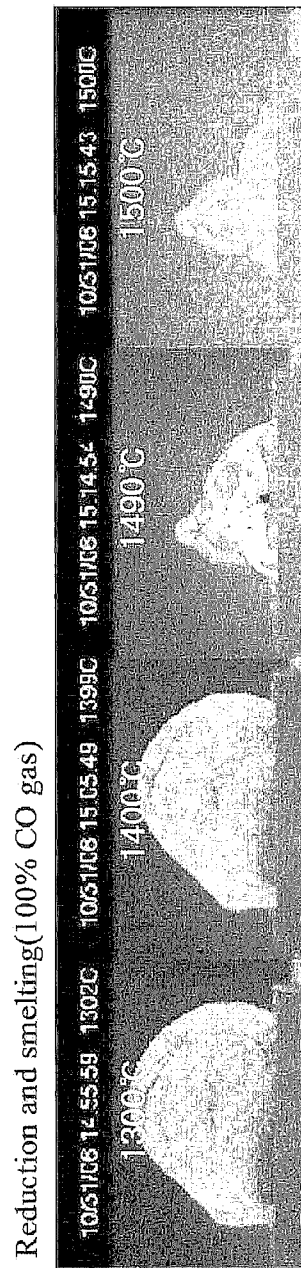


FIG. 15

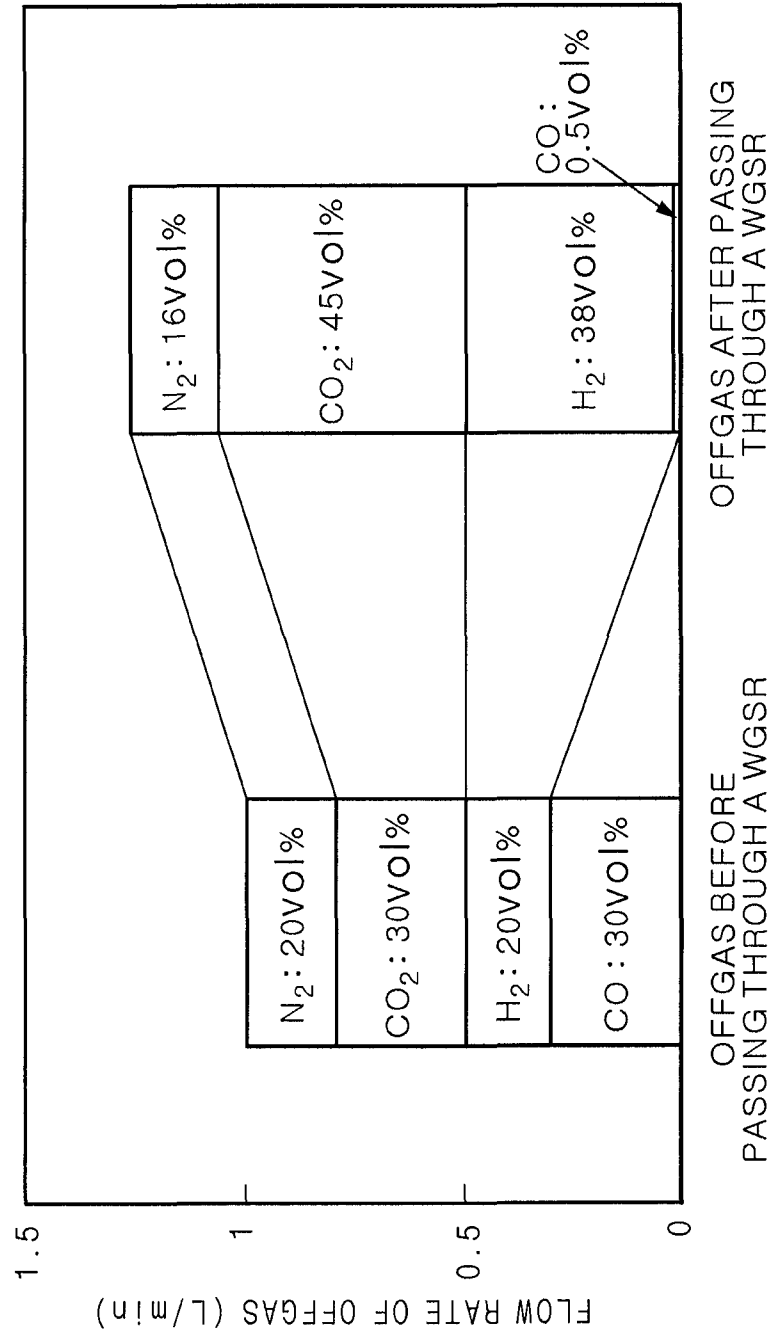


FIG. 16

