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(74) Agents: HAYNES, Elwood L. et al.; 2700 Post Oak Blvd., Suite 325, Houston, Texas 77056 (US).

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(71) Applicant: L'AIR LIQUIDE, SOCIETE ANONYME POUR L'ETUDE ET L'EXPLOITATION DES PROCEDES GEORGES CLAUDE [FR/FR]; 75, Quai d'Orsay, F-75007 Paris (FR).

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(72) Inventors; and  
(71) Applicants (for US only): GROVER, Bhadra S. [US/US]; 6526 Wexford Tr., Sugar Land, Texas 77479 (US). KAISER, Kenneth [US/US]; 163 Carlotta Drive, Bear, Delaware 19701 (US). GRANT, Michael G. K. [US/FR]; 57, rue Exelmans, Bâtiment 3, F-78000 Versailles (FR). HUANG, Wei [CN/US]; 91 Highland Circle, Newark, Delaware 19713 (US).

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(54) Title: USE OF OXYGEN FROM ION TRANSPORT MEMBRANES IN BLAST FURNACE

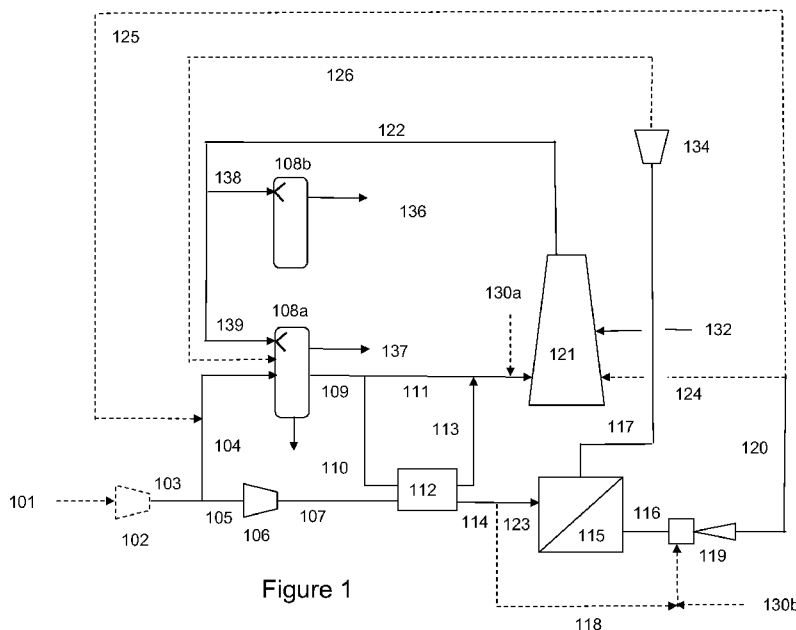


Figure 1

(57) Abstract: The present invention is a method of integrating oxygen production with blast furnace operation. A heated air stream is introduced to an ion transfer membrane separator, producing a permeate and a retentate. The permeate and the motive stream are introduced into an ejector jet pump producing an oxygen enriched stream. The oxygen enriched stream is introduced into blast furnace. In another embodiment of the present invention, the permeate and a steam motive stream are introduced into an ejector jet pump. Heated air inlet stream is introduced into a cascading series of ion transfer membrane separators, producing a series of permeate streams and a series of retentate streams wherein each retentate stream acts as the input stream for the subsequent ion transfer membrane separator. Thereby producing a series of oxygen enriched streams which are combined and introduced into blast furnace.

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## USE OF OXYGEN FROM ION TRANSPORT MEMBRANES IN BLAST FURNACE

### Background

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The blast furnace is a tall shaft-type furnace with a vertical stack superimposed over a crucible-like hearth. Iron-bearing materials (iron ore, sinter, pellets, mill scale, steelmaking slag, scrap, etc.), coke and flux (limestone and dolomite) are charged into the top of the shaft. A blast of heated air and also, in most instances, a gaseous, liquid or powdered fuel are introduced through openings at the bottom of the shaft just above the hearth crucible. The heated air burns the injected fuel and much of the coke charged in from the top to produce the heat required by the process and to provide reducing gas that removes oxygen from the ore. The reduced iron melts and runs down to the bottom of the hearth. The flux combines with the impurities in the ore to produce a slag which also melts and accumulates on top of the liquid iron in the hearth. The iron and slag are drained out of the furnace through tapholes.

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The top pressure that is controlled by the top gas handling equipment can be as high as (40-50 psig) for very large furnaces, and the blast air has been enriched with oxygen as high as 40% total oxygen in the blast. Pressure at the inlet of the tuyeres depends on the controlled top pressure and the quality of the raw materials, but can be as high as 60 psig for a very large blast furnace. Oxygen enrichment reduces the amount of air needed per tonne of iron and therefore, the resulting quantities of BF Top Gas are reduced.

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Ion transport membranes (ITMs) consist of ionic and mixed-conducting ceramic oxides that conduct oxygen ions at elevated temperatures of 1475 – 1650 F. Air is compressed to about 230 psia, heated to 1650 F, and fed to ITM. Hot oxygen permeates through the membranes. The permeate pressure has to be kept low to provide oxygen partial pressure driving force across the membrane. Typically, 50% to 80% oxygen recovery seems possible.

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## Summary

The present invention is a method of integrating oxygen production with blast furnace operation. A compressed air stream is divided into a blast furnace air stream and an ITM air stream. The blast furnace air stream is combined with an oxygen enriched stream and the combined stream is introduced into a blast furnace stove. The combined gas is then wherein it is heated, thereby producing heated blast furnace air stream, which is divided into a hot heat exchanger stream and a bypass heated stream. The ITM air stream is introduced into a heat exchanger, wherein it exchanges heat with the bypass hot heat exchanger stream, thereby producing cooled heat exchanger stream and warmed ITM stream. Cooled heat exchanger stream is then recombined with bypass heated stream and introduced into blast furnace. Warmed ITM stream is split into a ITM inlet stream and a motive stream. The ITM inlet stream is introduced into an ion transfer membrane separator, thereby producing a permeate stream and a retentate stream. The permeate stream and a motive stream are introduced into an ejector jet pump thereby producing the oxygen enriched stream, which is introduced into blast furnace. Alternately, a steam stream may be used as the motive stream for the ejector pump.

A system utilizing a series of ejector jet pumps is provided. Heated air inlet stream is introduced into a cascading series of ion transfer membrane separators thereby producing a series of permeate streams and a series of retentate streams wherein each retentate stream acts as the input stream for the subsequent ion transfer membrane separator. The permeate streams are introduced into a series of ejector jet pumps the ejector jet pumps using motive streams as motive fluid, thereby producing a series of oxygen enriched streams which are combined to form a combined oxygen enriched stream, which is introduced into blast furnace.

## Brief Description of the Figures

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Figure 1 is a schematic representation of one embodiment of the present invention. Figure 2 is a schematic representation of one embodiment of the present invention.

## Description of Preferred Embodiments

Illustrative embodiments of the invention are described below. While the invention is susceptible to various modifications and alternative forms, specific embodiments  
5 thereof have been shown by way of example in the drawings and are herein described in detail. It should be understood, however, that the description herein of specific embodiments is not intended to limit the invention to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the  
10 appended claims.

It will of course be appreciated that in the development of any such actual embodiment, numerous implementation-specific decisions must be made to achieve the developer's specific goals, such as compliance with system-related and  
15 business-related constraints, which will vary from one implementation to another. Moreover, it will be appreciated that such a development effort might be complex and time-consuming, but would nevertheless be a routine undertaking for those of ordinary skill in the art having the benefit of this disclosure.

20 To reduce the compression requirements for oxygen, a multi-stage membrane system is provided. The oxygen is withdrawn at successively reduced pressure.

In one, non-limiting example, oxygen may be withdrawn at 30, 16, 10, and 7. psia. The expected O<sub>2</sub> recovery at these stages is 27%, 39%, 20% and 14% respectively.  
25 In this example, the desired pressure of hot oxygen is 60 psia. An ejector is provided at each stage. The ejector for first two stages is being driven by hot blast air compressed to 145-230 psia. The last two stages of the ejectors are being driven by 580 psia steam. The choice of motive force for the driver depends upon the amount of hot air blast and steam required for the blast furnace. The ejectors can also be  
30 arranged in series/parallel arrangement to optimize the amount of motive streams driving the ejectors. In this example ejector 3&4 feed into ejector-2. The pressure of hot air and steam can be optimized based on extent of oxygen compression required.

There are many possibilities of integrating ITM process with BF. The BF blast air compressor may be used as a source of air for the ITM. BF air compressor typically supplies air at 60 – 75 psia. A booster compressor will raise the air pressure for ITM to 230 psia..

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The BF blast air can be used as motive force for thermo-compression of hot O<sub>2</sub> available at 7 – 30 psia. The O<sub>2</sub> needs to be compressed to about 45 - 60 psia. The pressure desired for the motive air will be higher (in the range of 145 - 220 psia) than the typically pressure of 60 – 75 psia for the blast air.

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Steam normally fed to BF can also be used as motive force for O<sub>2</sub> compression. Hot residue gas from ITM can be let down in a turbo-expander and mixed with BF top gas, before the top gas is combusted and sent to stoves for heat recovery. Oxygen present in the N<sub>2</sub> rich stream gets utilized for combustion of the BF top gas.

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Hot residue gas from ITM can be mixed with fuel, combusted to use O<sub>2</sub> present, let down in a turbo-expander and fed to the stove at some intermediate point.

The hot residue gas, downstream of turbo-expander, can be used to generate steam. The steam produced is used for motive steam for the ejectors, as described above. Or the steam is directly fed to the BF.

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Turning to Figure 1, a method of integrating oxygen production with blast furnace operation is provided. A dried air stream **101** is compressed in compressor **102**, thus creating a compressed, dried air stream **103**. The compressed, dried air stream **103** is divided into a blast furnace air stream **104** and an ITM air stream **105**. As used in this description, blast furnace stove **108a** is the active stove, and **108b** is the inactive stove. Compressed, dried air stream **103** may have a pressure of about 72 psia. The blast furnace air stream **104** is combined with oxygen enriched stream **125** and is introduced into blast furnace stove **108a**, wherein it is heated, thereby producing heated blast furnace air stream **109**. Blast furnace stove **108b** is heated with at least a portion **138** of blast furnace gas stream **122** in preparation for the above requirement to heat the combined blast furnace air stream **104** and oxygen enriched stream **125** once it is time to change the active stove. First combustion product stream **136** is then exhausted from the stove. Once the stove change takes

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place, blast furnace stove **108a** becomes the inactive stove, and at least a portion **139** of blast furnace gas stream **122** is used to preheat this stove. Second combustion product stream **137** is then exhausted from the stove.

5 Heated blast furnace air stream **109** may have a temperature of between 1800 and 2200 F. Heated blast furnace air stream **109** is then divided into a hot heat exchanger stream **110** and a bypass heated stream **111**. The ITM air stream **105** may be compressed in compressor **106**, thereby producing compressed ITM air stream **107**. Compressed ITM air stream **107** may have a pressure of about 230  
10 psia. Compressed ITM air stream **107**, or ITM air stream **105**, is introduced into a heat exchanger **112**, wherein it exchanges heat with the hot heat exchanger stream **110**, thereby producing cooled heat exchanger stream **113** and warmed ITM air stream **114**. Cooled heat exchanger stream **113** is recombined with bypass heated stream **111** and introduced into the blast furnace **121**.

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The warmed stream ITM air stream **114** is split into an ITM inlet stream **123** and a motive stream **118**. ITM inlet stream **123** may have a temperature of about 1475 to 1650 F. ITM inlet stream **123** is introduced to an ion transfer membrane separator  
20 **115**, thereby producing a permeate stream **116** and a retentate stream **117**. The retentate stream **117** may then pass through a pressure reduction turbine **134**. After pressure reduction, at least a portion **126** of retentate stream **117** may be introduced into active stove **108a** to provide additional heat. A blast furnace steam stream **130a** may be introduced into blast furnace **121**.

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The permeate stream **116** and the motive stream **118** are introduced into an ejector jet pump **119** thereby producing an oxygen enriched stream **120**. Oxygen enriched stream **120** may have a pressure of about 60 psia, and may have a temperature between 1475 and 1650 F. A portion **124** of oxygen enriched stream **120** may be  
30 introduced directly into blast furnace **121**. Oxygen enriched stream **124** may be introduced separated through individual lances in the tuyeres (not shown). A portion **125** of oxygen enriched stream **120** may combined with blast furnace air stream **104**, at the pressure required for the blast furnace, and then introduced into blast furnace

stove **108a**, wherein it is heated and combined with heated blast furnace air **109** prior to introduction into blast furnace **121**.

Retentate stream **117** may be expanded in expander **134**, thereby producing  
5 reduced pressure retentate stream **126**. At least a portion **138** of reduced pressure retentate stream **126** may be introduced into active BF Stove **108a**, as discussed above. Reduced pressure retentate stream **126** may also be used for other purposes, such as drying ground coal in the pulverized coal injection (PCI) plant. At least a portion **139** of blast furnace gas stream **122** is introduced into  
10 inactive BF stove **108b**, as discussed above.

Turning to Figure 2, one non-limiting example of a system utilizing a series of ejector jet pumps. Heated air inlet stream **114** is introduced into a cascading series of ion transfer membrane separators **115, 204, 211, 217**, thereby producing a series of  
15 permeate streams **116, 205, 212, 218** and a series of retentate streams **203, 210, 216, 117**, wherein each retentate stream acts as the input stream for the subsequent ion transfer membrane separator. The permeate streams **116, 205, 212, 218** are introduced into a series of ejector jet pumps **119, 208, 214, 220**, the ejector jet pumps using motive streams **201, 207, 213, 219** as motive fluid, thereby producing a  
20 series of oxygen enriched streams **202, 209, 215, 221**, which are combined to form a combined oxygen enriched stream **120**, which is introduced into blast furnace **121**.

In a more detailed description of Figure 2, heated air inlet stream **114** is introduced into a first ion transfer membrane separator **115**, thereby producing a first permeate  
25 stream **116** and a first retentate stream **203**. The first permeate stream **116** and a first motive stream **201** are introduced into a first ejector jet pump **119** thereby producing a first oxygen enriched stream **202**. The first retentate stream **203** is introduced into a second ion transfer membrane separator **204**, thereby producing a second permeate stream **205** and a second retentate stream **210**. A second  
30 combined oxygen enriched stream **222** and the second permeate stream **205** are combined, thereby producing a third combined oxygen enriched stream **206**.

The third combined oxygen enriched stream **206** and a second motive stream **207** are combined into a second ejector jet pump **208** thereby producing a second

oxygen enriched stream **209**. The second retentate stream **210** is introduced into a third ion transfer membrane separator **211**, thereby producing a third permeate stream **212** and a third retentate stream **216**. The third permeate stream **212** and a third motive stream **213** are introduced into a third ejector jet pump **214** thereby  
5 producing a third oxygen enriched stream **215**. The third retentate stream **216** is introduced into a fourth ion transfer membrane separator **217**, thereby producing a fourth permeate stream **218** and a fourth retentate stream **217**.

The fourth permeate stream **218** and a fourth motive stream **219** are introduced into  
10 a fourth ejector jet pump **220** thereby producing a fourth oxygen enriched stream **221**. The third oxygen enriched steam stream **215** and the fourth oxygen enriched stream **221** are combined thereby producing the second combined oxygen enriched stream **222**. The first oxygen enriched stream **202** and the second oxygen enriched stream **209** are combined thereby producing a first combined oxygen enriched  
15 stream **120** , which is introduced into blast furnace **121**.

At least one of the motive streams may be steam. At least one of the motive streams may be heated air, and at least one additional motive stream may be steam.

What is claimed is:

Claim 1. A method of integrating oxygen production with blast furnace operation,  
5 comprising;

a) dividing a compressed air stream (103) into a blast furnace air stream (104) and a ITM air stream (105),

10 b) combining the blast furnace air stream (104) with an oxygen enriched stream (125) and introducing the combined stream into a first blast furnace stove (108a), wherein it is heated, thereby producing heated blast furnace air stream (109), which is divided into a hot heat exchanger stream (110) and a bypass heated stream (111);

15 c) introducing at least a portion of a blast furnace gas stream (122) into a second blast furnace stove (108b), wherein it is used as fuel to heat the second blast furnace stove 108b,

d) introducing the ITM air stream (105), into a heat exchanger (112), wherein it exchanges heat with the hot heat exchanger stream (110), thereby producing cooled heat exchanger stream (113) and warmed ITM stream (114), cooled heat exchanger stream (113) then being  
20 recombined with bypass heated stream (111) and introduced into blast furnace (121);

e) splitting warmed ITM stream (114) into a ITM inlet stream (123) and a motive stream (118),

25 f) introducing ITM inlet stream (123) to an ion transfer membrane separator (115), thereby producing a permeate stream (116) and a retentate stream (117); and

introducing said permeate stream (116) and the motive stream (118) into an ejector jet pump (119) thereby producing the oxygen enriched stream (125), which is introduced into blast furnace (121).

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Claim 2. The method of claim 1, wherein said compressed air stream (103) is provided by a blast air compressor (102).

Claim 3. The method of claim 1, wherein said ITM air stream (105) is further compressed (106) prior to introduction into said heat exchanger (112).

Claim 4. The method of claim 1, further comprising:

- 5 e) introducing ITM inlet stream (123) to a cascading series of ion transfer membrane separators (115, 204, 211, 217), thereby producing a series of permeate streams (116, 205, 212, 218) and a series of retentate streams (203, 210, 216, 117), wherein each retentate stream acts as the input stream for the subsequent ion transfer membrane separator;
- 10 f) introducing the permeate stream (116, 205, 212, 218) into a series of ejector jet pumps (119, 208, 214, 220), the ejector jet pumps using motive stream (201, 207, 213, 219) as motive fluid, thereby producing a series of oxygen enriched streams (202, 209, 215, 221), which are combined to form a combined oxygen enriched stream (120), which is introduced into blast
- 15 furnace (121).

Claim 5: The method of claim 1, wherein steps e) and f) further comprise::

- i) introducing ITM inlet stream (123) to a first ion transfer membrane separator (115), thereby producing a first permeate stream (116) and a first retentate
- 20 stream (203);
- ii) introducing said first permeate stream (116) and a first motive stream (201) into a first ejector jet pump (119) thereby producing a first oxygen enriched stream (202);
- iii) introducing said first retentate stream (203) to a second ion transfer
- 25 membrane separator (204), thereby producing a second permeate stream (205) and a second retentate stream (210);
- iv) combining a second combined oxygen enriched stream (222) and said second permeate stream (205) thereby producing a third combined oxygen enriched stream (206);
- 30 v) introducing said third combined oxygen enriched stream (206) and a second motive stream (207) into a second ejector jet pump (208) thereby producing a second oxygen enriched stream (209);

- vi) introducing said second retentate stream (210) to a third ion transfer membrane separator (211), thereby producing a third permeate stream (212) and a third retentate stream (216);
- vii) introducing said third permeate stream (212) and a third motive stream (213) into a third ejector jet pump (214) thereby producing a third oxygen enriched stream (215);
- viii) introducing said third retentate stream (216) to a fourth ion transfer membrane separator (217), thereby producing a fourth permeate stream (218) and a fourth retentate stream (117);
- ix) introducing said fourth permeate stream (218) and a fourth motive stream (219) into a fourth ejector jet pump (220) thereby producing a fourth oxygen enriched stream (221);
- x) combining said third oxygen enriched steam stream (215) and said fourth oxygen enriched stream (221) thereby producing said second combined oxygen enriched stream (222); and
- xi) combining said first oxygen enriched stream (202) and said second oxygen enriched stream (209) thereby producing a first combined oxygen enriched stream (120) , which is introduced into blast furnace (121).

Claim 6: The method of claim 5, wherein at least one of said motive streams comprises steam.

Claim 7: The method of claim 5 wherein at least one of said motive streams comprises heated air, and at least one additional motive stream comprises steam.

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Claim 8: A method of integrating oxygen production with blast furnace operation, comprising;

- a) dividing a heated air inlet stream (103) into a blast furnace air stream (104) and a ITM air stream (105),
- b) combining the blast furnace air stream (104) with an oxygen enriched stream (125) and introducing the combined stream into a blast furnace stove (108a), wherein it is heated, thereby producing heated blast furnace air stream (109), which is divided into a hot heat exchanger stream (110) and a bypass heated stream (111);

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- c) introducing at least a portion of a blast furnace gas stream (122) into a second blast furnace stove (108b), wherein it is used as fuel to heat the second blast furnace stove (108b),
- d) introducing the ITM air stream (105), into a heat exchanger (112), wherein it exchanges heat with the hot heat exchanger stream (110), thereby producing cooled heat exchanger stream (113) and warmed ITM stream (114), cooled heat exchanger stream (113) then being recombined with bypass heated stream (111) and introduced into blast furnace (121);
- e) introducing ITM inlet stream (123) to an ion transfer membrane separator (115), thereby producing a permeate stream (116) and a retentate stream (117);
- f) introducing said permeate stream (116) and a steam motive stream (130b) into an ejector jet pump (119) thereby producing an oxygen enriched stream (120), which is introduced into blast furnace (121); and
- g) introducing at least a portion (226) of retentate stream (117) into a steam generator (129); thereby producing steam stream (130),
- h) dividing steam stream (130) into blast furnace steam stream (130a), which is introduced into blast furnace (121), and said steam motive stream (130b).

Claim 9: The method of claim 8, wherein said portion of retentate stream (117) passes through a pressure reduction turbine (133) prior to introduction into steam generator (129).

Claim 10: The method of claim 8, wherein said steam generator (129) is supplemental fired as needed.

Claim 11: The method of claim 8 wherein said heated air inlet stream (103) is provided by a blast air compressor (102).

Claim 12: The method of claim 8 wherein said heated air inlet stream (103) is further compressed (106) prior to introduction into said heat exchanger (112).

Claim 13: The method of claim 8, further comprising:

- 5 e) introducing warmed ITM stream (114) to a cascading series of ion transfer membrane separators (115, 204, 211, 217), thereby producing a series of permeate streams (116, 205, 212, 218) and a series of retentate streams (203, 210, 216, 117), wherein each retentate stream acts as the input stream for the subsequent ion transfer membrane separator;
- 10 f) introducing the permeate stream (116, 205, 212, 218) into a series of ejector jet pumps (119, 208, 214, 220), the ejector jet pumps using motive stream (201, 207, 213, 219) as motive fluid, thereby producing a series of oxygen enriched streams (202, 209, 215, 221), which are combined to form a combined oxygen enriched stream (120), which is introduced into blast furnace (121).

Claim 14: The method of claim 8, wherein steps e) and f) further comprise:

- 15 i) introducing warmed ITM stream (114) to a first ion transfer membrane separator (115), thereby producing a first permeate stream (116) and a first retentate stream (203);
- ii) introducing said first permeate stream (116) and a first motive stream (201) into a first ejector jet pump (119) thereby producing a first oxygen enriched stream (202);
- 20 iii) introducing said first retentate stream (2303) to a second ion transfer membrane separator (204), thereby producing a second permeate stream (205) and a second retentate stream (210);
- iv) combining a second combined oxygen enriched stream (222) and said second permeate stream (205) thereby producing a third combined oxygen enriched stream (206);
- 25 v) introducing said third combined oxygen enriched stream (206) and a second motive stream (207) into a second ejector jet pump (208) thereby producing a second oxygen enriched stream (209);
- 30 vi) introducing said second retentate stream (210) to a third ion transfer membrane separator (211), thereby producing a third permeate stream (212) and a third retentate stream (216);

- vii) introducing said third permeate stream (212) and a third motive stream (213) into a third ejector jet pump (214) thereby producing a third oxygen enriched stream (2315);
- viii) introducing said third retentate stream (216) to a fourth ion transfer  
5 membrane separator (217), thereby producing a fourth permeate stream (218) and a fourth retentate stream (117);
- ix) introducing said fourth permeate stream (218) and a fourth motive stream (219) into a fourth ejector jet pump (220) thereby producing a fourth oxygen enriched stream (221);
- 10 x) combining said third oxygen enriched steam stream (215) and said fourth oxygen enriched stream (221) thereby producing said second combined oxygen enriched stream (222); and
- xi) combining said first oxygen enriched stream (202) and said second oxygen enriched stream (209) thereby producing a first combined oxygen enriched  
15 stream (120) , which is introduced into blast furnace (121).

Claim 15: The method of claim 14, wherein at least one of said motive streams comprises heated air.

- 20 Claim 16: The method of claim 14, wherein at least one of said motive streams comprises heated air, and at least one additional motive stream comprises steam.



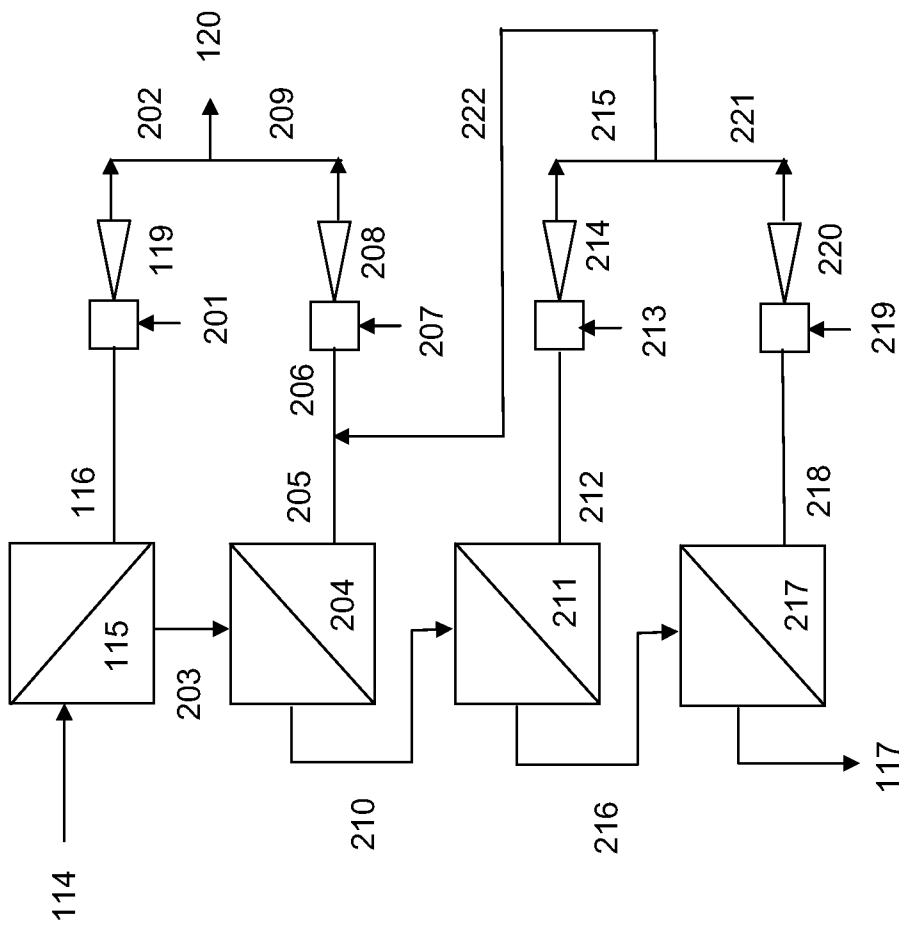


Figure 2