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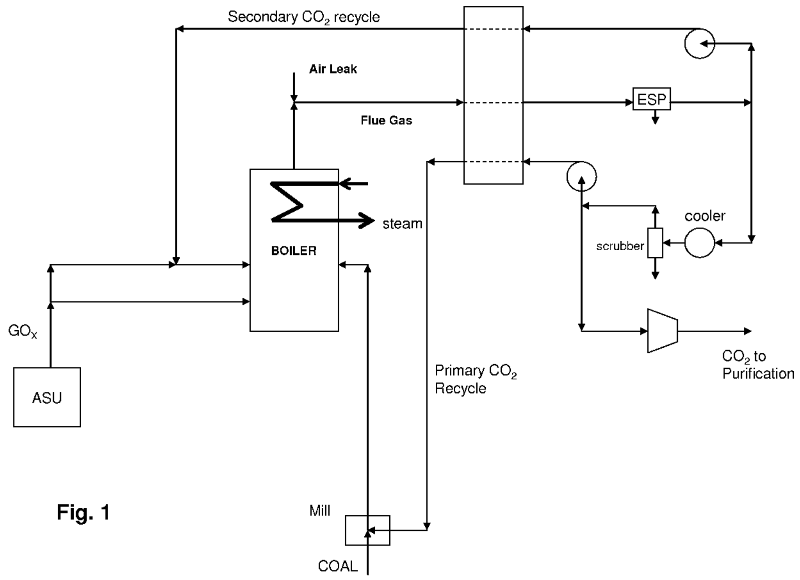

Fig. 1

(57) Abstract: An improved process for the separation of carbon dioxide from the flue gas of an oxy-combustion power plant is provided. The flue gas is compressed, cleaned, cooled and dried. This clean, compressed dry flue gas is then further cooled, partially condensed and separated into liquid and vapor streams. The liquid streams, which contain a high concentration of carbon dioxide, are vaporized, compressed and exported to an end user. The vapor streams are heated and expanded, in order to extract useable energy. At least two expanders are used to extract this energy, with an intermediate warming step.

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IMPROVED CO_2 SEPARATION APPARATUS AND PROCESS FOR OXY-COMBUSTION COAL POWER PLANTS

Background

It is believed that there are global warming effects that are being caused by the introduction of increased carbon dioxide into the atmosphere. One major source of carbon dioxide emission is the flue gas that is exhausted as a result of a power generation plant's combustion process. Therefore, there have been several efforts by governments and utility companies worldwide, to reduce these emissions.

There are two principal types of power plants that are based on combustion processes; coal combustion and natural gas combustion. Both of these processes produce carbon dioxide as a byproduct when generating power. Efforts have been made to increase the efficiency of the burner, and, therefore, the basic combustion process itself. The intent of these efforts has been to reduce carbon monoxide (the result of imperfect combustion), oxides of nitrogen, and other pollutants. However, since the production of carbon dioxide and water are the basic products of the chemical reaction of combustion, the most efficient technique to minimize the carbon dioxide emission is to capture as much of the carbon dioxide as possible as it is being created by the power plants. In order to truly maximize the efficiency of this technique, existing coal combustion plants, which represent a large portion of the power generation plants worldwide, must also be targeted. The oxy-combustion technique is very interesting, and has significant advantages, since it can be adapted to existing facilities.

Traditional power plants use air as the source of oxidant to combust the fuel (typically coal). Steam is generated by indirect heat exchange with the hot combustion products. The steam is then expanded in turbines to remove useful energy, and, thereby, produce power. The combustion process produces carbon dioxide as a by-product, which is mixed with the residual nitrogen of the combustion air. Due to the high content of nitrogen in the inlet air (78 mol %), the carbon dioxide is diluted in the flue gas. To insure full combustion, the power plants must also run with an excess air ratio that further dilutes the carbon dioxide in the flue gas. The concentration of carbon dioxide in the flue gas of an air combustion plant is typically about 20 mol %.

This dilution of the carbon dioxide increases the size and the power consumption of any carbon dioxide recovery unit. Because of this dilution, it becomes very costly and difficult to recover the carbon dioxide. Therefore, it is desirable to produce flue gas with at least about 90% to 95 mol % carbon dioxide, in order to minimize the abatement cost. The current technology for carbon dioxide recovery from flue gas utilizes amine contact tower to scrub out the carbon dioxide. However, the high amount of heat that is needed to regenerate the amine and extract the carbon dioxide, reduces the amine processes cost effectiveness.

In order to avoid the dilution of carbon dioxide in the nitrogen, the power generation industry is switching to an oxy-combustion process. Instead of utilizing air as an oxidant, high purity oxygen (typically about 95% purity or better) is used in the combustion process. The combustion heat is dissipated in the recycled flue gas concentrated in the carbon dioxide. This technique makes it possible to achieve a flue gas containing between about 75 mol % and 95 mol % carbon dioxide. This is a significant improvement over the previous concentration of about 20 mol %, which is obtained with air combustion. The purity of carbon dioxide in oxy-combustion's flue gas ultimately depends on the amount of air leakage into the system and the purity of oxygen being utilized. The necessary high purity oxygen is supplied by an air separation unit.

In one example of the traditional oxy-combustion process, the carbon dioxide removal process begins as the flue gas exiting the boiler is cooled and sent to an electrostatic precipitator. A portion of the flue gas is further cooled, the moisture is removed, and this portion of the flue gas is recycled to the coal handling section (mill, dryer, etc). Another portion of the flue gas is recycled back to the boiler, and the remaining portion is extracted as flue gas output and is sent to the carbon dioxide purification unit. One example of this type of oxy-combustion is illustrated in Figure 1.

Since pure oxygen, hence power input and capital cost, is required in the oxy-combustion process to facilitate the capture of carbon dioxide, the whole process, including the oxygen plant and the carbon dioxide capture and purification must be very efficient to minimize the power consumption. Otherwise, the economics of the carbon dioxide recovery will become unattractive to the operator of the power generation plant. In summary, the carbon dioxide capture with oxy-combustion is appealing in terms of pollution abatement, however, in order to achieve it, the capital expenditure and the power input must be minimized to avoid a prohibitive increase in power cost.

As previously mentioned, carbon dioxide purities of 90% or higher (typically 95% or higher) are desirable for many subsequent carbon dioxide abatement techniques (such as deep well injection, deep sea injection or enhanced oil recovery systems). Due to air leakage and the presence of inert gases in the high purity oxygen (nitrogen and argon), in practice the flue gas can be as low as about 75% carbon dioxide. The carbon dioxide concentration must therefore be increased to 90% to 95% in some type of purification process. Common industry specifications typically require that the overall carbon dioxide recovery ratio must be about 90% and even higher than 95% in some cases.

On example, of such a purification system, was described in the Publication of IEA Green House R&D Programme-Oxycombustion

Processes for CO_2 Capture From Power Plant (Report Number 2005/9, dated July, 2005). This process is illustrated in Figure 2.

In the process indicated in Figure 2, the flue gas is washed. Its acid content is removed, it is compressed to a pressure greater than about 30 bar, then it is dried (stream 1). A cryogenic partial condensation process is then utilized to concentrate the carbon dioxide (stream 7 and stream 8).

The carbon dioxide is further compressed to very high pressure (between about 80 bar and about 120 bar) (stream 9). The off-gas leaving the process at 30 bar (stream 10) is generally heated to about 300°C, then it is expanded in a hot gas expander in order to more efficiently recover the potential energy.

In order to heat to 300°C, the gas must be heated first to about 150°C by exchanging heat with an adiabatic compressor (i.e. the compression heat is not removed by an intercooler, and the exit temperature is allowed to rise to about 200°C). The gas is then heated to 300°C by heat exchange with the flue gas from the boiler.

As evidence of these thermal costs, it is noted that an adiabatic compressor (either feed gas or carbon dioxide compressor) consumes more power than the isothermal compressor equipped with intercoolers. Also, the hot gas expander, because of the high expansion ration, (about 30 to 1) and high operating temperature, requires a multiple stage (usually axial type) expander. The skilled artisan will recognize that this type of expander is typically quite expensive. And the heating of the off-gas from about 150°C to about 300°C by the flue gas consumes the valuable heat of the boiler, and, therefore, it is possible that steam production will be effected. This will then result in a lower power output from the stream turbines. This reduces the efficiency of the overall process. This also requires a gas-to-gas heat exchanger in the boiler, which, is typically, very expensive. Furthermore, utility companies involved with oxycombustion are also evaluating techniques to minimize the air leakage to further improve the CO_2 content of flue gases. This effort also reduces the flowrate of the off-gas stream, such that its recoverable energy becomes smaller, compared with the total power input. Therefore, it becomes less attractive to use less efficient adiabatic compressors to recover the reduced power content of lower off-gas flow.

In another example of the existing art, European patent number 0503910 presents a process scheme, wherein the compressed dry flue gas is treated in 2 distillation columns arranged in series. The first column removes the inert gases (O_2, N_2 and Argon) and produces a bottom liquid containing CO_2, acid gases, and less than 5 ppm O_2. This liquid then feeds in the second column, which then yields the pure CO_2 overhead liquid and the acid gases bottom liquid. Since these products are in liquid form, this process requires intensive cooling by external refrigeration equipment and additional nitrogen expansion by the oxygen plant. The inert gas extracted from the flue gas is expanded in 3 expanders in series with intermediate reheats to keep the exhaust temperatures of the expanders above the freezing point of CO_2.

For the foregoing reasons, a need exists for a more cost effective and efficient method for removing carbon dioxide from the flue gas that is generated by oxy-combustion plants. In particular, a need exists for a method that recovers energy from the expansion of the off-gas stream in a more efficient and cost effective manner.

Summary

The present invention is directed to a method that satisfies the need in general for a more cost effective and efficient method for removing carbon dioxide from the flue gas that is generated by oxy-combustion plants.

In one aspect of the present invention, an improved carbon dioxide separation process for oxy-combustion coal power plants is provided. This process requires warming at least a portion of a waste stream, that has been separated from a flue gas stream. This waste stream is then expanded, which results in a cool vapor exhaust stream.

Brief Description of the Drawings

For a further understanding of the nature and objects for the present invention, reference should be made to the following detailed description, taken in conjunction with the accompanying drawings, in which like elements are given the same or analogous reference numbers and wherein:

- Figure 1 is a stylized diagram of an illustrative embodiment of an oxy-combustion process for a coal power plant;
- Figure 2 is a stylized diagram of an illustrative embodiment of a typical partial condensation process with a hot gas expander;
- Figure 3 is a stylized diagram of an illustrative embodiment of the present invention having two separators to remove carbon dioxide from the flue gas, and two expanders to remove energy from the off-gas stream;
- Figure 4 is a stylized diagram of an illustrative embodiment of the present invention having a stripping column and a separator, and two expanders to remove energy from the off-gas stream;
- Figure 5 is a stylized diagram of an illustrative embodiment of the present invention having distillation column and two separators, and two expanders to remove energy from the off-gas stream;
- Figure 6 is a stylized diagram of an illustrative embodiment of the present invention having two distillation columns and two

separators, and two expanders to remove energy from the off-gas stream; and

- Figure 7 is a stylized diagram of another illustrative embodiment of the present invention having striping column and two separators, and two expanders to remove energy from the off-gas stream.

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 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 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 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.

Figure 3 depicts an illustrative embodiment of process **300** according to the present invention. Process **300** includes a first separator **310**, a second separator **312**, a first pressure increasing device **320**, a second pressure increasing device **323**, a first expander **315**, a second expander **318**, a first heat transfer device **331**, a second heat transfer device **332**, a first pressure reducing device **326**, a second pressure reducing device **314**, and a collective heat transfer device, which is indicated generally as **329** in Figure 3.

Flue gas from the oxycombustion power plant is available at essentially atmospheric pressure and relatively warm temperature. After cooling to about ambient temperature, the flue gas is then compressed, the compression heat is removed in the compressor's cooler, the compressed flue gas stream is then dried in dryer **330**. Examples of such drying methods may include, but are not limited to, desiccant dehumidification system, adsorption system by activated alumina or molecular sieves, permeation dryers or solvent scrubber/dryers. The flue gas also contains some other impurities, mainly the by-products of the coal combustion, such as traces of acid, NO_x (like nitrogen oxide NO and nitric oxide NO_2), SO_x (like sulfur dioxide SO_2, sulfur trioxide SO_3) etc. In some circumstances, it is preferable to remove some of these impurities in a scrubber system prior to cryogenic treatment. For example, NO_2 can react with water and SO_2 in the scrubber to yield sulfuric acid or, in the absence of SO_2 or if SO_2 is depleted, can react with water to yield nitric acid. With sufficient residence time, NO can react with oxygen to form NO_2, which, is then converted to the acids, as described. The acids in the water can be neutralized with a hydroxide solution or some other chemical means. The choice of front-end removal of those impurities depends upon the final use of CO_2 and the economics of wet treatment of flue gas. Indeed, the NO_2 and SO_2 being heavier than CO_2 would concentrate in the CO_2 product. The presence of SO_2, NO_2, and sometimes O_2 and NO, in the CO_2 can be objectionable for sequestration or EOR applications. In this situation, these impurities can be removed in the front-end treatment so that CO_2 will not contain significant level of those impurities.

Once the compressed flue gas stream is cooled and dried, and its impurities optionally removed, to form compressed dry flue gas stream **301**, it is further cooled **302** and sent to a first separator **310**. The compressed dry flue gas stream **301** may be at a pressure of about 30 bar, its temperature can be between about 5ºC and about 35ºC. It is possible to perform the drying of the flue gas at a lower pressure followed by further compressing the dry flue gas to the required pressure for cryogenic treatment. The further cooled flue gas stream **302** will be at least partially condensed. Within the first separator **310**, this further cooled flue gas stream **302** is separated into a first vapor stream **303** and a first liquid stream **311**. This first liquid stream **311** may be comprised of at least 90% carbon dioxide. The first vapor stream **303** is further cooled and at least partially condensed **304**, and sent to a second separator **312**. The at least partially condensed stream **304** may have a temperature of about -52°C. Within the second separator **312**, this further cooled first vapor stream **304** is separated into a second vapor stream **305** and a second liquid stream **313**. This second liquid stream **313** may be comprised of at least 90% carbon dioxide.

The second liquid stream **313** is warmed and vaporized **307**. This warmed and vaporized stream **307** may have a pressure of about 9 bar and a temperature as low as of about -40°C. The colder temperature lowers the compression power of the carbon dioxide compressor. The temperature is preferably warmer than the dew point of the gas, so sending liquid droplets into the compressor inlet can be avoided. The -40ºC minimum temperature allows the use of lower cost carbon steel and not higher cost stainless steel for piping and compression equipment. The second liquid stream **313** may pass through a second pressure-reducing device **314**. After passing through the second pressure-reducing device **314**, the second liquid steam **313** may have a pressure of about 9 bar. The vaporized second liquid stream **307** is compressed in a first pressure-increasing device **320**, thereby, creating a higher-pressure stream **321**. A portion of the second liquid stream **313** may remain a liquid **334**. The first liquid stream **311** may pass through a first pressure-reducing device **326**. After passing through the first pressure reducing device **326** the first liquid stream may have a pressure of about 19 bar and may have a temperature of about -6°C. The at least a portion of the first liquid stream **311** is warmed and vaporized **308**, at which point it combines with stream **321** to produce a combined stream **322**. A portion of the first liquid stream **311** may remain a liquid **333**. Combined stream **322** is further compressed in a second pressure-increasing device **323**, thereby, creating a high-pressure stream **309**.

The second vapor stream **305** is warmed in exchanger **329** and further warmed in first heat transfer device **331** to a temperature higher than that of the flue gas **301**, thereby, resulting in a warm third vapor stream **324**. This warm third vapor stream **324** may have a temperature that is between about 35°C and about 80°C. This warm third vapor stream **324** is then expanded in a first expander **315**, thereby, resulting in a cool fourth vapor stream **316**. This cool fourth vapor stream **316** may have a pressure of about 6.6 bar. This cool fourth vapor stream **316** is then warmed in exchanger **329** and further warmed in exchanger **332** to a temperature higher than that of the flue gas **301**, thereby, resulting in a warm fifth vapor stream **317**. This warm fifth vapor stream **317** may have a temperature that is between about 35°C and about 80°C. This warm fifth vapor stream **317** is then expanded to about atmospheric pressure in a second expander **318**, thereby, resulting in a cool sixth vapor stream **319**. This cool sixth vapor stream **319** is then warmed and vented.

Power generated by first expander **315** or second expander **318** can be used to drive electric generators to produce electricity, or can be used to partially drive the boost compressor (not shown) for the feed gas **301**, or carbon dioxide product (first or second pressure increasing devices **320** or **323**).

The external heat exchanger used to heat the off-gas (first and second heat transfer devices **331** and **332**) may be a heat recovery exchanger, wherein the hot compressed feed gas or hot compressed carbon dioxide exchanges heat with the off-gas to provide the necessary heat. These heat exchangers can be an intercooler, or aftercooler of the flue gas compressor, or carbon dioxide product compressors (first or second pressure increasing devices **320** or **323**). In most isothermal compressors, the gas exiting a compressor stage is usually about 90℃ to about 120℃, and it can be used as heating medium, therefore, heating to the level of about 50℃ can suit very well for the isothermal compressor, which is favorable for any power saving scheme.

Thanks to the refrigeration supplied by the first and second expanders **315** and **318**, the carbon dioxide fractions **311** and **313** can be produced at low temperature, ranging from about -40℃ to about 3℃. Furthermore, this additional refrigeration also allows extracting the CO_2 streams **307** and **308** at higher pressures to save more compression power.

Since the triple point of carbon dioxide is -56.6℃, it is preferable to limit the outlet temperature of the first and second expanders **315** and **318** to about -54℃ to avoid the risk of carbon dioxide freezing at the cold end of the exchanger. This constraint can be met by using the first and second expanders **315** and **318**, with inlet temperature about 35℃ to about 70℃ and to expand from about 30 bar to about atmospheric pressure as proposed in the present application. A single expander would yield an outlet temperature that was too cold, and would require a higher expander inlet temperature, which is more difficult to achieve, as in the case of the hot gas expander. Without heating to about 35℃ to about 70℃, it is also feasible to obtain similar performance of the 2 expanders by using 3 expanders in series with inlet temperatures of about 10℃ to about 20℃. However, not only is there an additional cost for the third expander, also the heat exchanger would cost higher due to an additional passage for the third expander flow.

In some situations, it is desirable to produce a CO_2 product essentially free of oxygen like in applications for Enhanced Oil Recovery (EOR). Figure 4 depicts an illustrative embodiment of process **400** for oxygen removal according to the present invention. Process **400** includes a first separator **414**, a second separator **453**, a stripping column **440**, a first pressure increasing device **420**, a second pressure increasing device **422**, a third pressure increasing device **432**, a fourth pressure increasing device **437**, a fifth pressure increasing device **418**, first expander **425**, a second expander **428**, a first heat transfer device **451**, a second heat transfer device **452**, a first pressure reducing device **417**, a second pressure reducing device **430**, and a collective heat transfer device, which is indicated generally as **441** in Figure 3.

Once the compressed flue gas stream **401** is cooled and dried, a portion **404** is sent to a stripping column **440** reboiler wherein it serves as the reboiler inlet stream **404**. The stripping column **440** may operate at about 10 bar. The stripping column **440** may operate at between about 10 bar and about 25 bar. This flue gas stream **404** reboils the stripping column **440** by condensing at least a portion of the flue gas stream **404** in the reboiler. This reboiler inlet stream **404** then exits the stripping column's reboiler as the reboiler outlet stream **405**. Stream **405** is sent to a second separator **453**, where it is separated into the reboiler outlet vapor stream **455** and reboiler outlet liquid stream **456**. Reboiler outlet liquid stream **456** feeds the stripping column. Reboiler outlet vapor stream **455** is then further cooled, and will be at least partially condensed, thereby, resulting in separator inlet stream **457**. The remaining portion **403** of the flue gas is cooled, partially condensed to yield stream **406**. Within the first separator **414**, streams **406** and **457** are separated into a first vapor stream **415** and a first liquid stream **416**. This first liquid stream **416** is then sent to a first pressure-reducing device **417**, thereby, resulting in a stripping feed stream **413**. This stripping feed stream **413** is then sent to the stripping **440**.

The stripping overhead stream **407** is warmed **402**, and then sent to a fifth pressure-increasing device **418**, thereby, creating a recycle steam **419**. Of course, the warmed stripping overhead stream can feed to a stage of the flue gas compressor thus simplifying the machine arrangement at the expense of a slightly larger drying unit. The warmed and vaporized stripping column overhead stream **402** may have a temperature that is between about 35°C and about 40°C. This recycle stream **419** is then combined with flue gas stream **401**.

A portion of the stripping column bottom stream **408** is sent to a first pressure increasing device **420**, which results in a first medium pressure liquid stream **421**. The stripping column bottom stream **408** contains less than 10 ppmv of oxygen. This first medium pressure liquid stream **421** is then warmed and vaporized, then sent to a second pressure increasing device **422**, thereby, resulting in a high pressure stream **423**. This high-pressure stream **423** is then sent to the end-user.

The first vapor stream **415** is warmed in exchanger **441** to about ambient temperature and further warmed in exchanger **451** to a temperature higher than that of the flue gas **401**, thereby, resulting in a first warm vapor stream **424**. This first warm vapor stream **424** may have a temperature that is between about 35°C and about 80°C. This first warm vapor stream **424** is then expanded in a first expander **425**, thereby, resulting in a cool second vapor stream **426**. This cool second vapor stream **426** is then warmed in exchanger **441** to about ambient temperature and further warmed in exchanger **452** to a temperature higher than that of the flue gas **401**, thereby, resulting in a second warm vapor stream **427**. This second warm vapor stream **427** may have a temperature that is between about 35°C and about 80°C. This second warm vapor stream **427** is then expanded in a second expander **428**, thereby, resulting in a cool third vapor stream **429**. This cool third vapor stream **429** is then warmed and vented.

In another embodiment, as illustrated in both Figure 4 and Figure 4a, a portion of the stripping column bottom stream **408** is removed prior to the first pressure-increasing device **420**. This removed portion is sent to a second pressure reducing device **430**, and warmed and vaporized, thereby, creating a low-pressure stream **431**. This low-pressure stream **431** is then compressed in a third pressure increasing device **432**, thereby, creating a second medium pressure stream **433**.

In another embodiment, as illustrated in both Figure 4 and Figure 4a, a portion of the stripping column bottom stream **408** is removed after the first pressure-increasing device **420**. This removed portion is sent to a third pressure reducing device **434**, and warmed and vaporized, thereby, creating an intermediate-pressure stream **454**. This intermediate-pressure stream **454** is then compressed in a fourth pressure increasing device **437**, thereby, creating a second medium-pressure stream **439**. This second-medium pressure stream **439** is then combined with the first medium-pressure stream **421**, prior to admission into the second pressure increasing device **422**.

Power generated by first expander **425** or second expander **428** can be used to drive electric generators to produce electricity, or can be used to partially drive the boost compressor for the feed gas **401**, or carbon dioxide product **432**, **437**, or **422**.

The external heat exchanger used to heat the off-gas **451** and **452** may be a heat recovery exchanger wherein the hot compressed feed gas or hot compressed carbon dioxide exchanges heat with the off-gas to provide the necessary heat. These heat exchangers can be an intercooler or aftercooler of the flue gas **401** or carbon dioxide product compressors **431**, **437**, or **422**. In most isothermal compressors, the gas exiting a compressor stage is usually about 90℃ to about 120℃, and it can be used as heating medium, therefore, heating to the level of about 50℃ can suit very well for the isothermal compressor, which is favorable for any power saving scheme.

Thanks to the refrigeration supplied by the 2 expanders **425** and **428**, the carbon dioxide fractions can be extracted at low temperature, ranging from about -40℃ to about 3℃. This additional refrigeration also allows extracting the CO_2 product streams at higher pressures to save more compression power.

Since the triple point of carbon dioxide is -56.6°C, it is preferable to limit the outlet temperature of the expanders **425** and **428** to about -54°C to avoid the risk of carbon dioxide freezing at the cold end of the exchanger. This constraint can be met by using 2 expanders **425** and **428** with inlet temperature about 35°C to about 70°C and to expand from about 30 bar to about atmospheric pressure as proposed in the present application. A single expander would yield an outlet temperature that was too cold, and would require a higher expander inlet temperature which is more difficult to achieve as in the case of the hot gas expander. Without heating to about 35°C to about 70°C, it is also feasible to obtain similar performance of the 2 expanders by using 3 expanders in series with inlet temperatures of about 10°C to about 20°C. However, not only is there an additional cost for the third expander, also, the heat exchanger would cost higher due to an additional passage for the third expander flow.

In another embodiment, as illustrated in Figures 5, the compressed dry flue gas **560** is sent to a distillation column **580** to remove the SO_2 and NO_2 impurities. A bottom stream **570** containing the captured SO_2 and NO_2 impurities is recovered and sent to the SO_2 and NO_2 treatment units. A vapor stream **565** exiting the top of the distillation column is essentially free of SO_2 and NO_2 and is further cooled and partially condensed. The vapor and liquid fractions of the partial condensation steps then follow the similar paths as in Figure 3. This type of process arrangement can be used when the CO_2 product can contain some oxygen, but only traces of SO_2 or NO_2.

The embodiment of Figure 6 is similar to Figure 5, a distillation column **680** for SO_2 and NO_2 removal is provided near the warm end of the heat exchanger **641**. The top vapor **665**, essentially free of SO_2 and NO_2, is cooled and partially condensed in the similar paths as in Figure 4. This type of process arrangement can be used when the CO_2 product contains only traces of oxygen, SO_2, and NO_2.

In another embodiment, as illustrated in Figure 7, a first portion of the compressed dry flue gas **701** is sent to a first phase separation device **703**, wherein it is separated into a first vapor stream **704** and a first liquid stream **705**. A second portion of the compressed dry flue gas **702** is cooled in the condenser of a stripping column **706**, then sent to a second phase separation device **710**, wherein it is separated into a second vapor stream **711** and a second liquid stream **712**. Second liquid stream **712** is sent to stripping column **706**, wherein it is separated into a third vapor stream **707** and a third liquid stream **708**. Third vapor stream **707** is then cooled and recirculated back to the incoming flue gas line. Third liquid stream **708**, is warmed and vaporized, then compressed and sent to an end user **709**. First liquid stream **705** is heated and sent to stripping column **706**. First vapor stream **704** is warmed in exchanger **713** to a temperature higher than that of the flue gas, thereby, resulting in a warm fourth vapor stream **714**. This warm fourth vapor stream **714** may have a temperature that is between about 35°C and about 80°C. This warm fourth vapor stream **714** is then expanded in a first expander **715**, thereby, resulting in a cool fifth vapor stream **716**. This cool fifth vapor stream **716** may have a pressure of about 6.6 bar. This cool fifth vapor stream **716** is then warmed in exchanger **717** to a temperature higher than that of the flue gas, thereby, resulting in a warm sixth vapor stream **718**. This warm sixth vapor stream **718** may have a temperature that is between about 35°C and about 80°C. This warm sixth vapor stream **718** is then expanded to about atmospheric pressure in a second expander **719**, thereby, resulting in a cool seventh vapor stream **720**. This cool seventh vapor stream **720** is then warmed and vented.

CLAIMS:

1. An improved carbon dioxide separation process for oxy-combustion coal power plants comprising;
   a) warming at least a portion of waste stream separated from a flue gas stream, and
   b) expanding said waste stream, thereby resulting in a cool vapor exhaust stream.

2. The process of claim 1, further comprising repeating steps a) and b) at least once.

3. The process of claim 1, further comprising;
   c) warming and venting said cool vapor exhaust stream.

4. The process of claim 1, wherein said cool vapor exhaust stream cools said flue gas stream through indirect heat exchange.

5. The process of claim 1, wherein said waste stream separation from said flue gas stream comprises;
   i) cooling a compressed dry flue gas, partially condensing and phase separating said cooled dry flue gas into a first vapor stream and a first liquid stream,
   ii) further cooling said first vapor stream, partially condensing and phase separating said further cooled first vapor stream into a second vapor stream and a second liquid stream,

wherein said waste stream comprises said first vapor stream and said second vapor stream.

6. The process of claim 5, wherein said cool vapor exhaust stream is vented.

7. The process of claim 5, wherein steps i) and ii) comprise;

iii) warming and vaporizing said first liquid stream, and said second liquid stream;

iv) warming said second vapor stream, thereby, resulting in a warm third vapor stream;

v) expanding said third vapor stream, thereby, resulting in a cool fourth vapor stream;

vi) warming said fourth vapor stream, thereby, resulting in a warm fifth vapor stream;

vii) expanding said fifth vapor stream, thereby, resulting in a cool sixth vapor stream; and

viii) warming and venting said sixth vapor stream.

8. The process of claim 7, wherein said third vapor stream has a temperature of between about 35°C to about 80°C.

9. The process of claim 7, wherein said fifth vapor stream has a temperature of between about 35°C to about 80°C.

10. The process of claim 7, wherein said first liquid stream comprises at least 90% carbon dioxide

11. The process of claim 7, wherein said second liquid stream comprises at least 90% carbon dioxide.

12. The process of claim 7, wherein said vaporized and warmed first and second liquid streams of step (iii) are extracted at a temperature of between about 35°C and -40°C.

13. The process of claim 7, wherein said vaporized and warmed first and second liquid streams of step (iii) are further compressed.

14. The process of claim 5, wherein the SO_2 and NO_2 impurities of the compressed dry flue gas are removed in a distillation column prior to said partially condensing and phase separating of step (i).

15. The process of claim 1, wherein said waste stream separation from said flue gas stream comprises;

i) cooling a compressed dry flue gas, partially condensing and phase separating said cooled dry flue gas into a first vapor stream and a first liquid stream, and

ii) feeding the first liquid stream into a stripping column,

wherein said waste stream comprises said first vapor stream.

16. The process of claim 15, wherein steps i) and ii) comprise;

iii) warming the first vapor stream to yield a first warm vapor stream;

iv) expanding the first warm vapor stream to yield a second vapor stream;

v) warming the second vapor stream to yield a second warm vapor stream; and

vi) expanding the second warm vapor stream to yield a third vapor stream.

17. The process of claim 16, further comprising:

vii) recovering a top vapor stream of the stripping column; and

viii) recovering a bottom liquid stream of the stripping column containing less than 10 ppmv of oxygen.

18. The process of claim 17, wherein said top vapor stream of step (vii) is warmed and mixed with the flue gas.

19. The process of claim 17, wherein said bottom liquid of step (viii) is vaporized and warmed.

20. The process of claim 17, wherein a portion of said bottom liquid of step (viii) is further pressurized by pump, warmed, and vaporized.

21. The process of claim 17, wherein a portion of said bottom liquid of step (viii) is warmed, vaporized, and mixed with flue gas.

22. The process of claim 19, wherein the warmed and vaporized bottom liquid is further compressed to higher pressure.

23. The process of claim 22, wherein the temperature of the warmed and vaporized bottom liquid is between about 35°C and about -40°C prior to being further compressed.

24. The process of claim 17, wherein said stripping column is reboiled by condensing a portion of flue gas stream in its reboiler.

25. The process of claim 16, wherein the SO_2 and NO_2 impurities of the compressed dry flue gas are removed in a distillation column prior to said partially condensing and phase separating of step (i).

26. The process of claim 5, wherein steps i) and ii) comprise;

iii) warming and vaporizing at least a portion of said first liquid stream, and at least a portion of said second liquid stream, thereby, creating a high pressure vapor stream;

iv) warming said second vapor stream, thereby, resulting in a warm third vapor stream;

v) expanding said third vapor stream, thereby, resulting in a cool fourth vapor stream;

vi) warming said fourth vapor stream, thereby, resulting in a warm fifth vapor stream;

vii) expanding said fifth vapor stream thereby, resulting in a cool sixth vapor stream; and

viii) warming and venting said sixth vapor stream.

27. The process of claim 26, wherein said third vapor stream has a temperature of between about 35°C to about 80°C.

28. The process of claim 26, wherein said fifth vapor stream has a temperature of between about 35°C to about 80°C.

29. The process of claim 5, wherein said first liquid stream comprises at least 90% carbon dioxide

30. The process of claim 5, wherein said second liquid stream comprises at least 90% carbon dioxide.

31. The process of claim 26, wherein said warmed and vaporized first and second liquid streams of step (iii) are extracted at a temperature of between about 35°C and about -40°C.

32. The process of claim 26, wherein said warmed and vaporized first and second liquid streams of step (iii) are further compressed.

33. The improved process of claim 5, wherein the SO_2 and NO_2 impurities of the compressed dry flue gas are removed in a distillation column prior to said partially condensing and phase separating of step (i).

34. The process of claim 26, wherein at least a portion of said first liquid stream remains a liquid.

35. The process of claim 26, wherein at least a portion of said second liquid stream remains a liquid.

36. The process of claim 1, wherein said waste stream separation from said flue gas stream comprises;

i) compressing a flue gas in a first compressor, then drying said compressed flue gas;

ii) cooling a first portion of said compressed dry flue gas, partially condensing and phase separating in a first phase separation device, into a first vapor stream, and a first liquid stream;

iii) cooling a second portion of said compressed dry flue gas, partially condensing and phase separating in a second phase separation device, into a second vapor stream, a second liquid stream;

iv) heating said first liquid stream, thereby, producing a heated first stream, and introducing said heated first stream into a stripping column;

v) cooling said second vapor stream, thereby, producing a cooled second stream, and introducing said cooled second stream into said first phase separation device;

vi) introducing said second liquid stream into said stripping column, therein producing a third vapor stream and a third liquid stream;

vii) heating said third vapor stream and recirculating this heated vapor stream back to said first compressor;

wherein said waste stream comprises said first vapor stream.

37. The process of claim 36, wherein steps i) and ii) comprise;

viii) warming and vaporizing said third liquid stream;

ix) warming said first vapor stream, thereby, resulting in a warm fourth vapor stream;

x) expanding said fourth vapor stream, thereby, resulting in a cool fifth vapor stream;

xi) warming said fifth vapor stream, thereby, resulting in a warm sixth vapor stream;

xii) expanding said sixth vapor stream, thereby, resulting in a cool seventh vapor stream; and

xiii) warming and venting said seventh vapor stream..

38. The process of claim 37, wherein said second portion of said compressed dry flue gas comprises about 10 to 20% of the total compressed dry flue gas.

39. The process of claim 37, wherein the mass flow rate of said third vapor stream is about 10 to 20% of the mass flow rate of the total compressed dry flue gas.

40. The process of claim 37, wherein said fourth vapor stream has a temperature of between about 35°C to about 80°C.

41. The process of claim 37, wherein said sixth vapor stream has a temperature of between about 35°C to about 80°C.

42. The process of claim 37, wherein said second liquid stream comprises at least 90% carbon dioxide.

43. The process of claim 37, wherein said warmed and vaporized second liquid stream of step (iii) is extracted at a temperature of between about 35°C and about -40°C.

44. The process of claim 37, wherein said warmed and vaporized second liquid stream of step (iii) is further compressed.

45. The process of claim 37, wherein the SO_2 and NO_2 impurities of the compressed dry flue gas are removed in a distillation column prior to said partially condensing and phase separating of step (ii).

46. An improved carbon dioxide separation apparatus for oxy-combustion coal power plants comprising;

a) a first separator for separating a cooled, compressed, and partially condensed dry flue gas into a first vapor stream, a first liquid stream;

b) a second separator for separating said first vapor stream that has been further cooled and partially condensing into a second vapor stream, a second liquid stream;

c) a first heat exchanging device for warming and vaporizing said first liquid stream, and said second liquid stream;

d) a second heat exchanging device for warming said second vapor stream, thereby, resulting in a warm third vapor stream;

e) a first expander for expanding said third vapor stream, thereby, resulting in a cool fourth vapor stream;

f) a third heat exchanging device for warming said fourth vapor stream, thereby, resulting in a warm fifth vapor stream;

g) a second expander for expanding said fifth vapor stream, thereby, resulting in a cool sixth vapor stream; and

h) a fourth heat exchanging device for warming said sixth vapor stream which is then vented.

47. The improved carbon dioxide separation apparatus of claim 46, wherein said first heat exchanging device, said second heat exchanging

device, said third heat exchanging device, and said fourth heat exchanging device are combined.

48. An improved carbon dioxide separation apparatus for oxy-combustion coal power plants comprising;

a) a separator for separating a cooled, compressed, and partially condensed dry flue gas into a first vapor stream, a first liquid stream;

b) a stripping column for stripping the first liquid stream to yield a bottom liquid stream of the stripping column containing less than 10 ppmv of oxygen;

c) a first heat exchanging device for warming the first vapor stream to yield a first warm vapor stream;

d) a first expander for expanding the first warm vapor stream to yield a second vapor stream;

e) a second heat exchanging device for warming the second vapor stream to yield a second warm vapor stream; and

f) a second expander for expanding the second warm vapor stream to yield a third vapor stream.

49. The improved carbon dioxide separation apparatus of claim 48, wherein said first heat exchanging device and said second heat exchanging device are combined.

50. An improved carbon dioxide separation apparatus for oxy-combustion coal power plants comprising;

a) a first separator for separating a cooled, compressed, and partially condensed dry flue gas into a first vapor stream, a first liquid stream;

b) a second separator for separating said first vapor stream that has been further cooled and partially condensed into a second vapor stream, a second liquid stream;

c) a first heat exchanging device for warming and vaporizing at least a portion of said first liquid stream, and at least a portion of said second liquid stream, thereby, creating a high pressure vapor stream;

d) a second heat exchanging device for warming said second vapor stream, thereby, resulting in a warm third vapor stream;

e) a first expander for expanding said third vapor stream, thereby, resulting in a cool fourth vapor stream;

f) a third heat exchanging device for warming said fourth vapor stream, thereby, resulting in a warm fifth vapor stream;

g) a second expander for expanding said fifth vapor stream, thereby, resulting in a cool sixth vapor stream; and

h) a fourth heat exchanging device for warming said sixth vapor stream which is then vented.

51. The improved carbon dioxide separation apparatus of claim 50, wherein said first heat exchanging device, said second heat exchanging device, said third heat exchanging device, and said fourth heat exchanging device are combined.

52. An improved carbon dioxide separation apparatus for oxy-combustion coal power plants comprising;

a) a first compressor for compressing a flue gas;

b) a dryer for drying said compressed flue gas;

c) a first separator for separating said cooled, compressed dry flue gas which has been further cooled and partially condensed into a first vapor stream, and a first liquid stream;

d) a first heat exchanging device for cooling and partially condensing a second portion of said compressed dry flue gas;

e) a second separator for separating said partially condensing second portion into a second vapor stream, and a second liquid stream;

f) a second heat exchanging device for heating said first liquid stream, thereby, producing a heated first stream;

g) a third heat exchanging device for cooling said second vapor stream, thereby, producing a cooled second stream, wherein said cooled second stream is introduced into said first phase separation device;

h) a third separator for separating said heated first stream and said second liquid stream into a third vapor stream and a third liquid stream;

i) a fourth heat exchanging device for heating said third vapor stream and recirculating this heated vapor stream back to said first compressor;

j) a fifth heat exchanging device for warming and vaporizing said third liquid stream;

k) a sixth heat exchanging device for warming said first vapor stream, thereby, resulting in a warm fourth vapor stream;

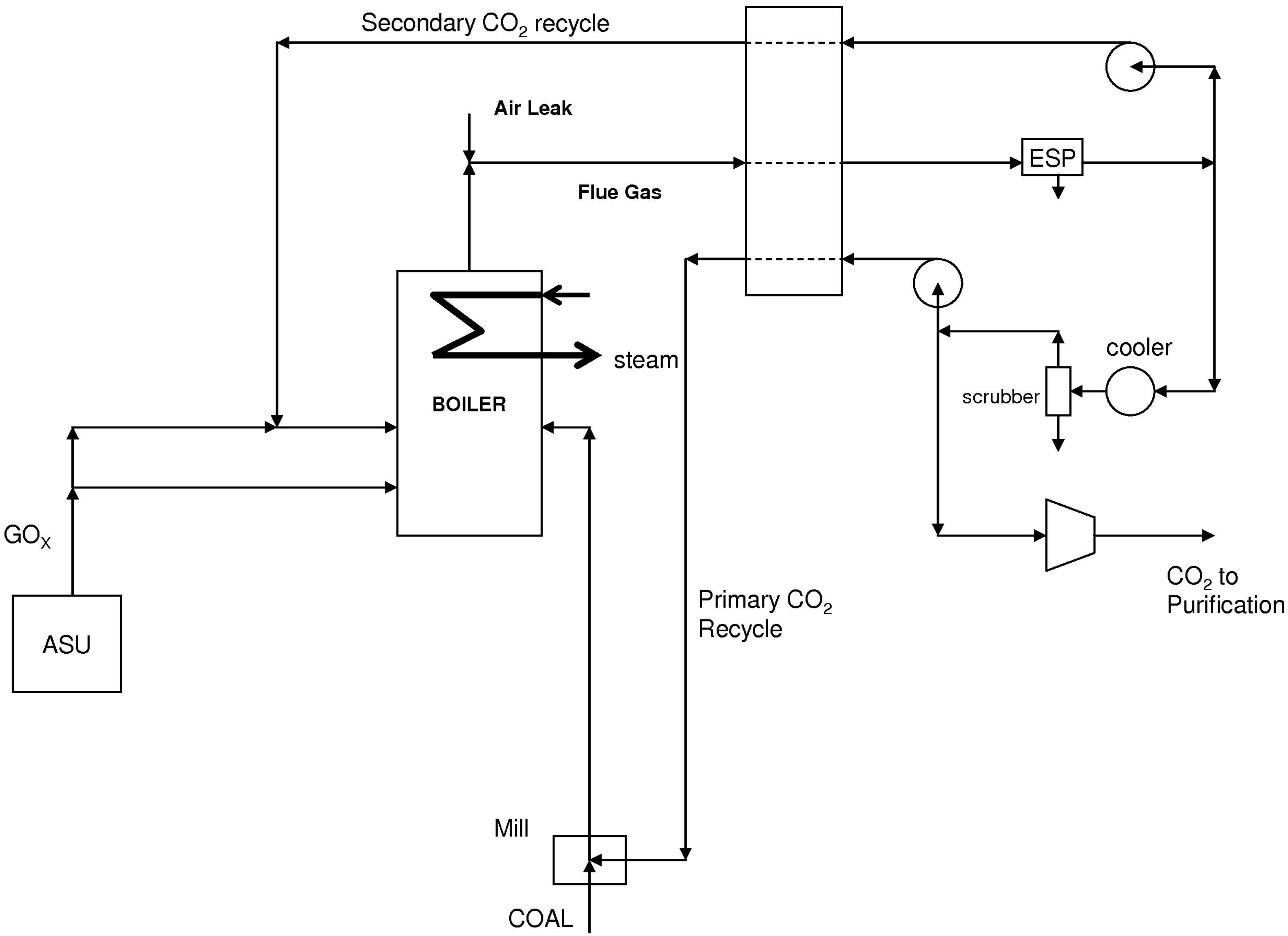
l) a first expander for expanding said fourth vapor stream, thereby, resulting in a cool fifth vapor stream;

m) a seventh heat exchanging device for warming said fifth vapor stream, thereby, resulting in a warm sixth vapor stream;

n) a second expander for expanding said sixth vapor stream, thereby, resulting in a cool seventh vapor stream; and

o) a eighth heat exchanging device for warming said seventh vapor stream which is then vented.

53. The improved carbon dioxide separation apparatus of claim 52, wherein said first heat exchanging device, said second heat exchanging device, said third heat exchanging device, and said fourth heat exchanging device, said fifth heat exchanging device, said sixth heat exchanging device, said seventh heat exchanging device, and said fourth heat exchanging device are combined.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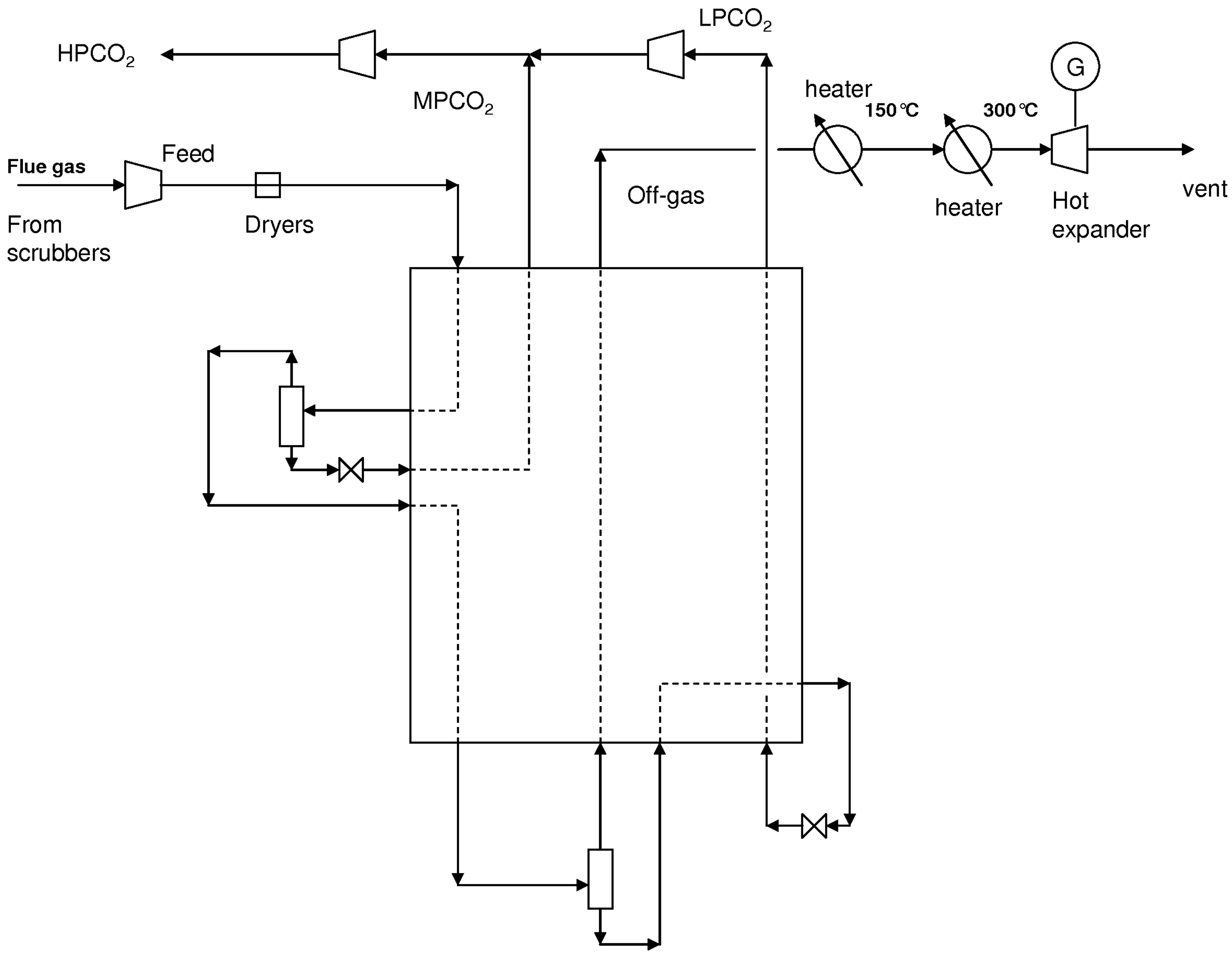
Air Leak
ESP
Flue Gas
steam
BOILER
cooler
scrubber
GO_X
ASU
CO_2 to Purification
Primary CO_2 Recycle
Mill
COAL

Fig. 1


HPCO2
LPCO2
MPCO2
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Dryers
Off-gas
heater
Hot
expander
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Fig. 2

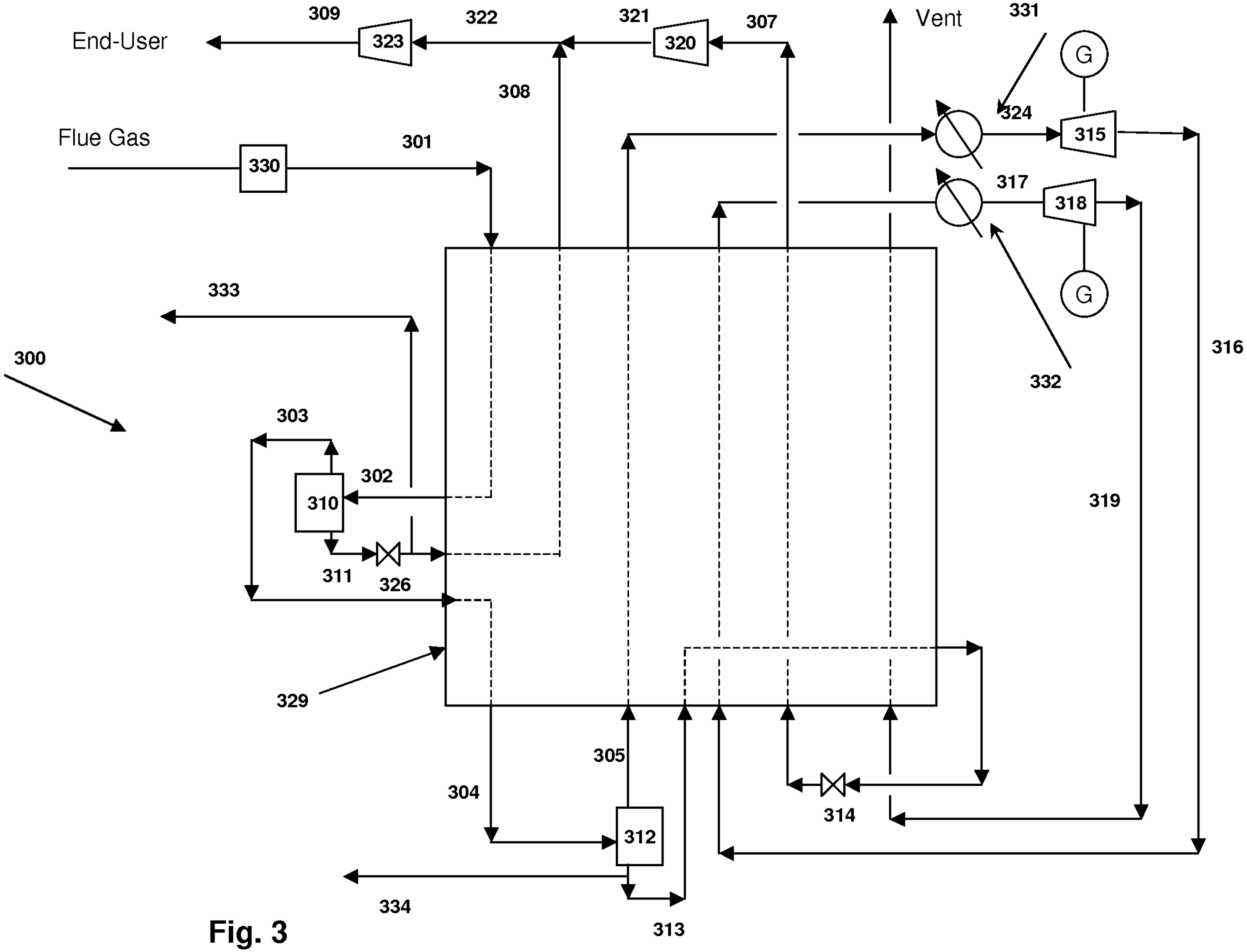
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Fig. 3

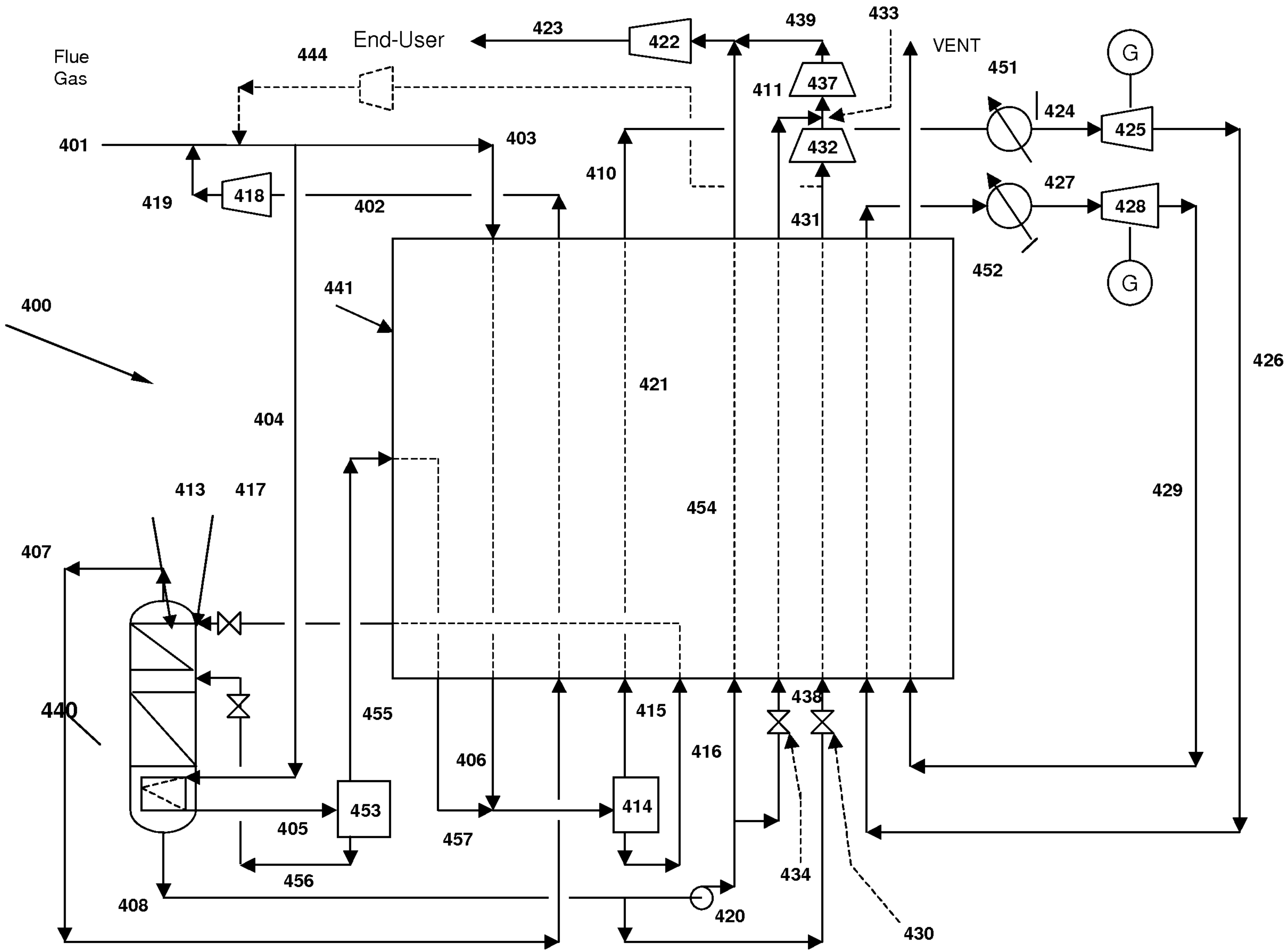
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Fig. 4

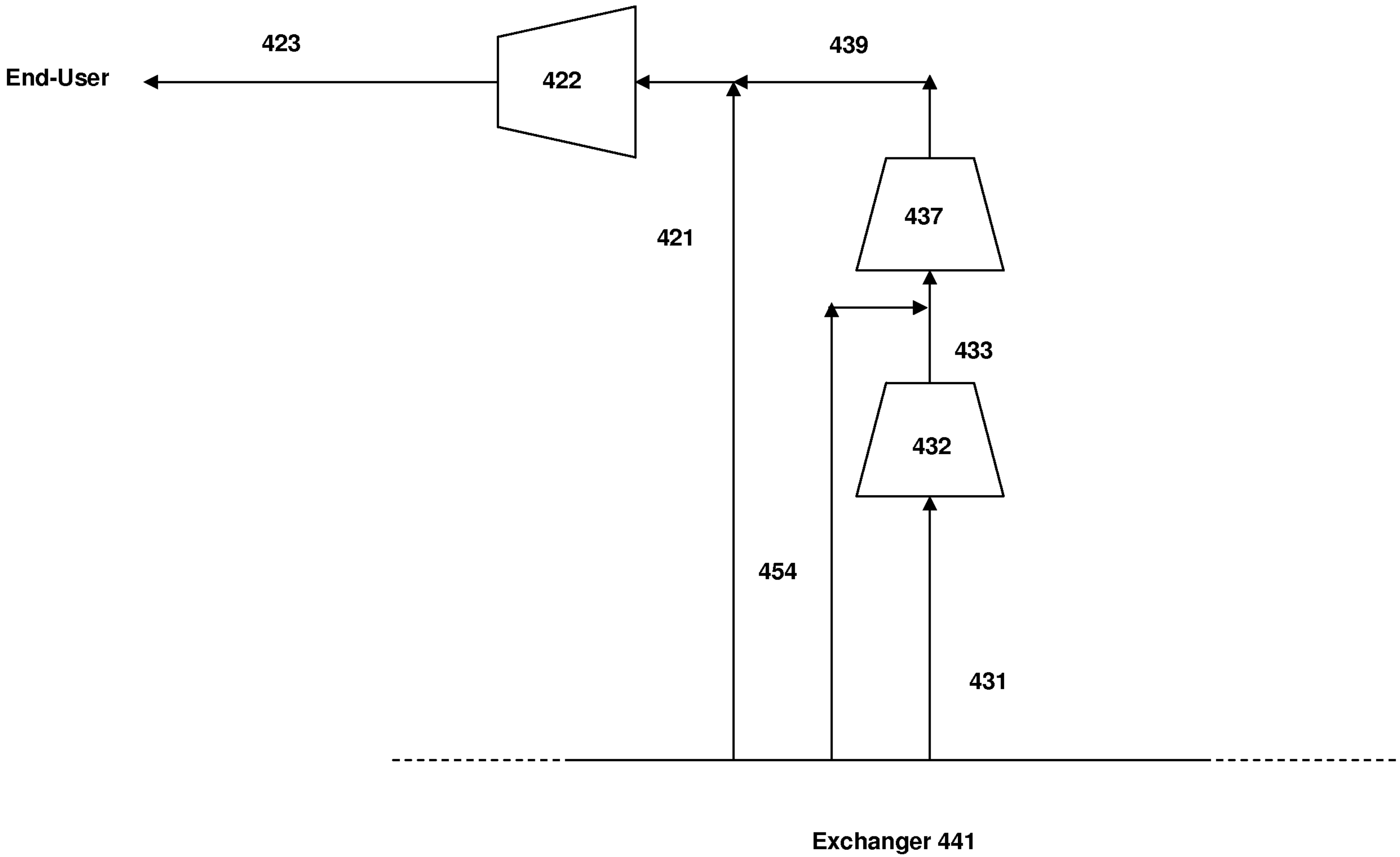

Fig. 4a

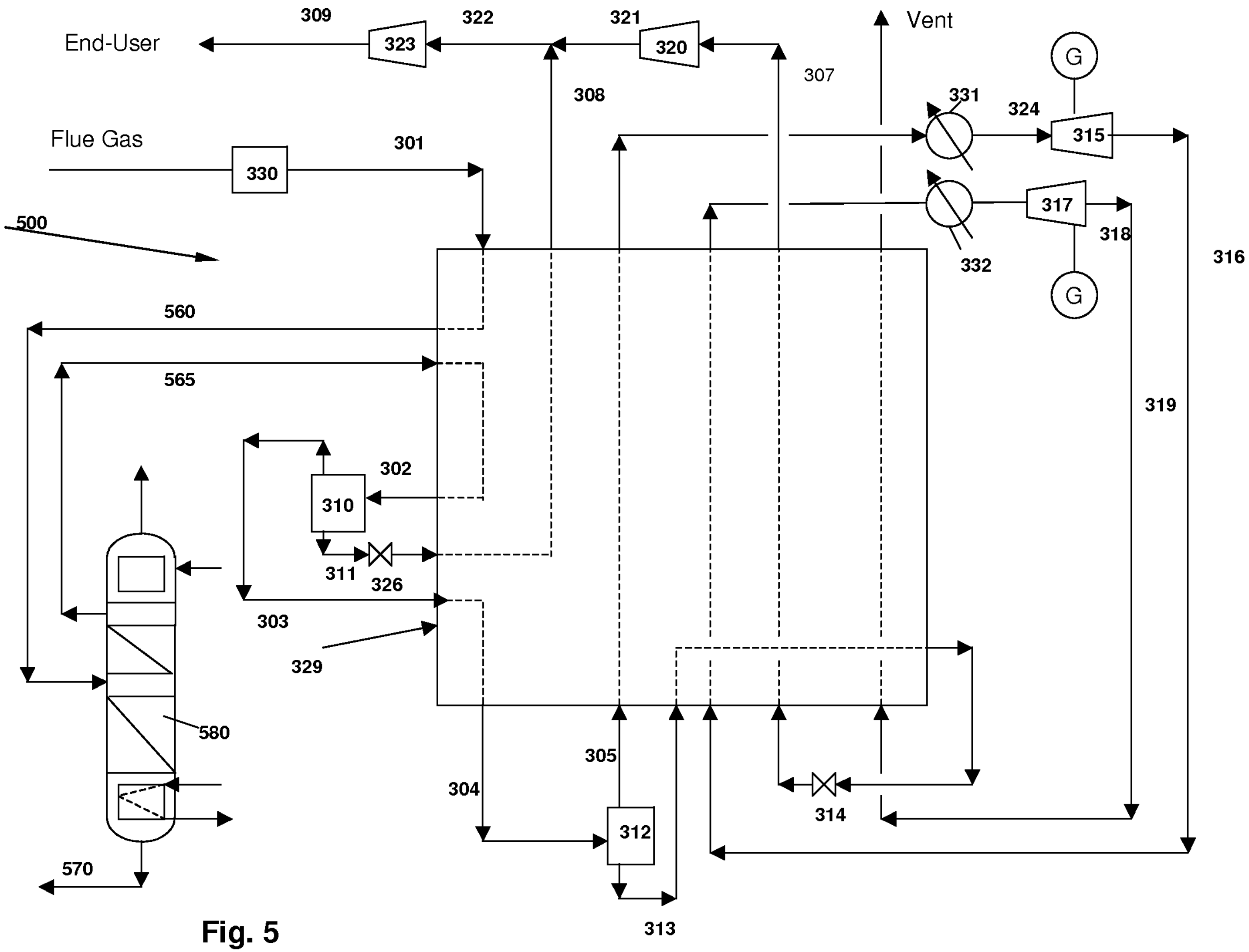
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Fig. 5

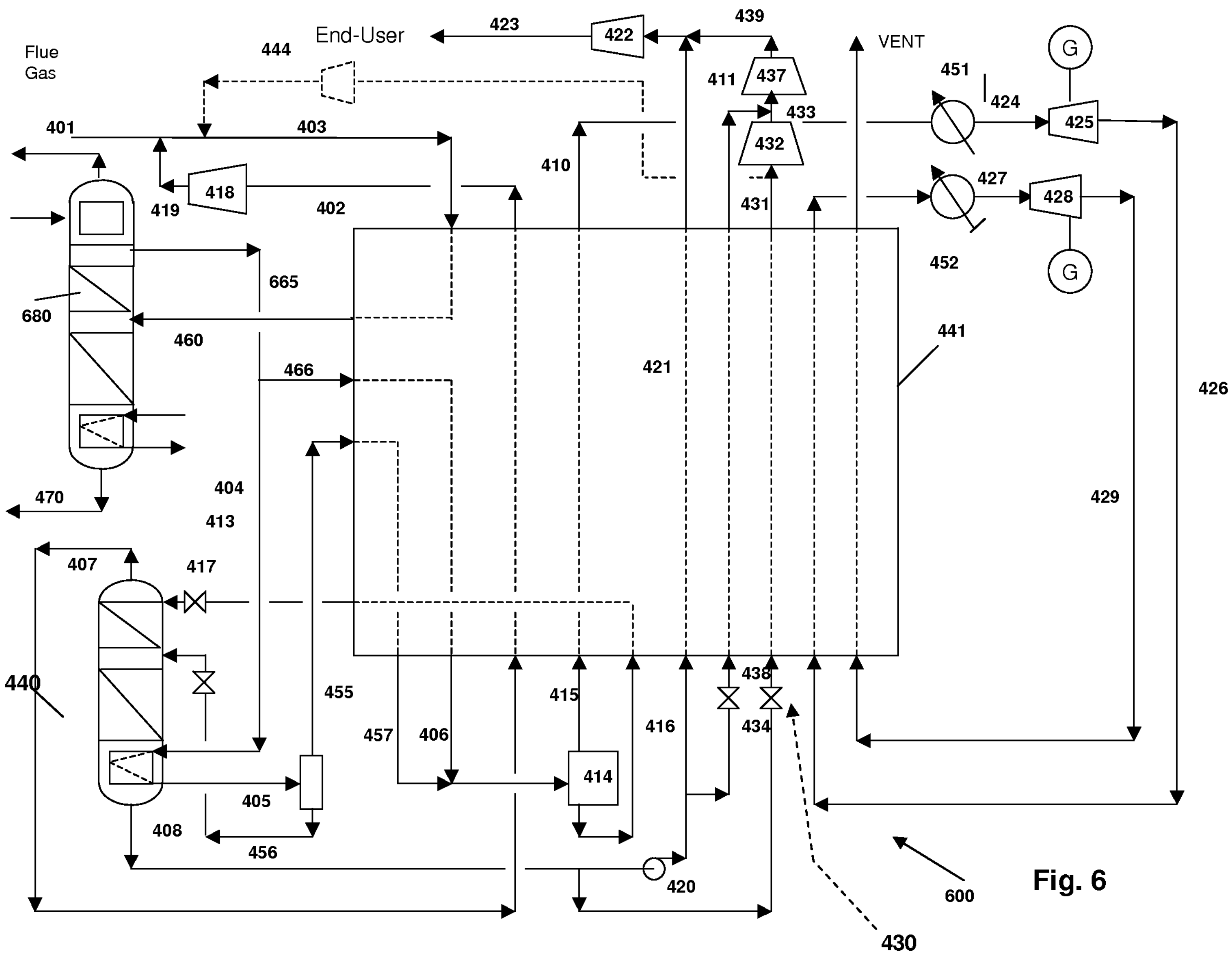
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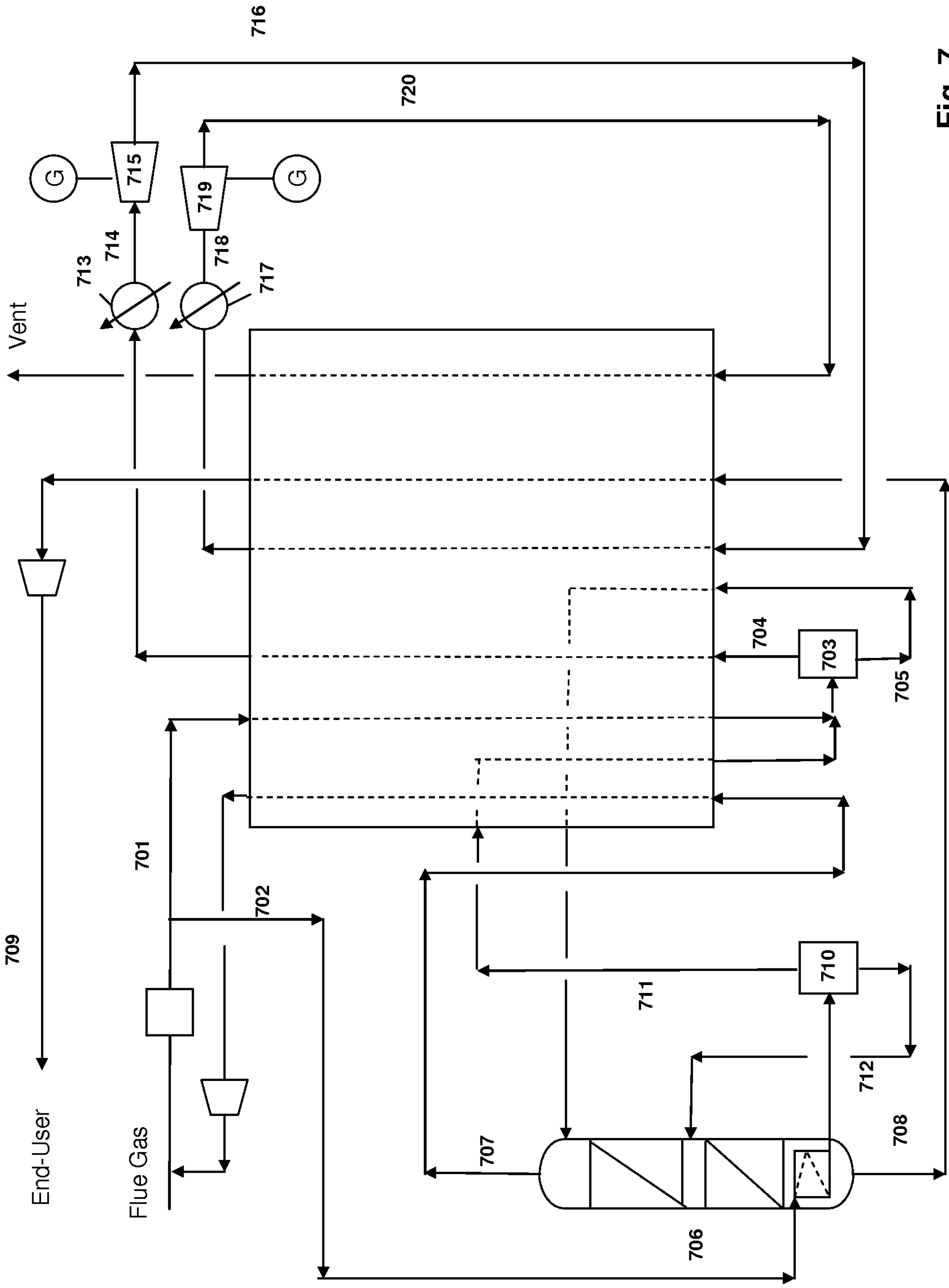
Fig. 6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End-User
Flue Gas

Fig. 7