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(54) METHOD AND APPARATUS FOR CRYOGENIC AIR SEPARATION

(57) A method of cryogenic air separation using an air separation unit (100) comprising a main air compressor (1), a main heat exchanger (2), a Lachmann turbine (3), a medium pressure turbine (4), a cold booster (5) mechanically coupled to either the Lachmann turbine (3) or the medium pressure turbine (4), and a rectification column system (10) including a pressure column (11) and a low-pressure column (12) is proposed, wherein at least 90% of a total quantity of air supplied to the rectification column system (10) is compressed in the main air compressor (1) to a pressure level which is at least 2 bar above an operating pressure level of the pressure column (11). A first part of the total air quantity is, after the compression in the main air compressor (1), subjected, as Lachmann air, to a turboexpansion in the Lachmann turbine (3) and is injected into the low-pressure column (12). A second part of the total air quantity is, after the compression in the main air compressor (1), cooled in the main heat exchanger (2), thereafter subjected to a turboexpansion in the medium pressure turbine (4), and thereafter injected into the rectification column system (10), and a third part of the total air quantity is, after the compression in the main air compressor (1), cooled in the main heat exchanger (2), thereafter subjected to a compression in the cold booster (5), and thereafter injected into the rectification column system (10). The first part of the total air quantity is subjected to a post-expansion cooling step after its expansion in the Lachmann turbine (3) and before its injection into the low-pressure column (12). A corresponding air separation unit (100) is also part of the invention.

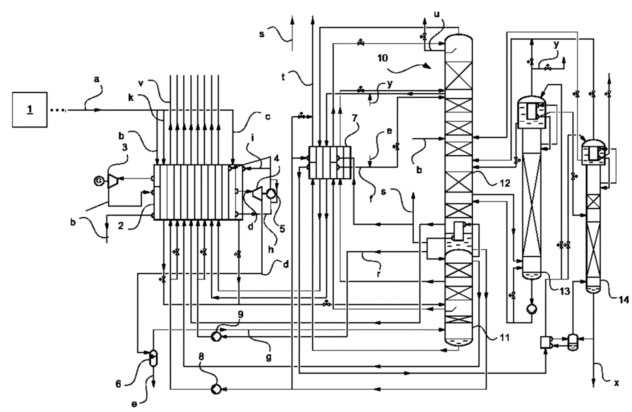

Fig. 4

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Description

[0001] The invention relates to a method and an apparatus for cryogenic air separation.

Background

[0002] The production of air products in liquid or gaseous state by cryogenic separation of air in air separation plants or air separation units (ASU) is well known and described, for example, in H.-W. Häring (eds.), Industrial Gases Processing, Wiley-VCH, 2006, especially section 2.2.5, "Cryogenic Rectification".

[0003] Classical air separation units comprise rectification column systems which can be designed, for example, as two-column systems, especially double-column systems, but also as three- or multi-column systems. In addition to rectification columns for the recovery of nitrogen and/or oxygen in liquid and/or gaseous state, i.e. rectification columns for nitrogen-oxygen separation, rectification columns can be provided for the recovery of other air components, in particular of noble gases.

[0004] The rectification columns of the rectification column systems just mentioned are typically operated in different pressure ranges. Classical double-column systems comprise a so-called pressure column (also referred to as high pressure column, medium pressure column or lower column) and a so-called low-pressure column (upper column). The pressure column is classically operated in a pressure range of 4 to 7 bar, especially at about 5.3 bar, whereas the low-pressure column is operated in a pressure range of typically 1 to 2 bar, especially at about 1.4 bar. In certain cases, higher pressures can also be used in said rectification columns. The pressures given here and below are absolute pressures at the top of the respective columns.

[0005] For air separation, so-called main air compressor/booster air compressor (MAC-BAC) processes and so-called high air pressure (HAP) processes can be used. Main air compressor/booster air compressor processes are typically considered more conventional while high air pressure processes are increasingly used as alternatives recently. A high air pressure process is used in the context of the present invention.

[0006] Main air compressor/booster air compressor processes are characterized by the fact that only a part of the total feed air quantity supplied to the rectification column system is compressed to a pressure in a pressure range which is considerably higher than the pressure range in which the pressure column is typically operated. A further part of the feed air quantity is compressed to a pressure in this pressure range only, or at most to a maximum pressure of 1 to 2 bar above this pressure range, and is fed into the pressure column without further expansion. An example of such a process is for example shown in Figure 2.3A of Häring (see above).

[0007] In a high air pressure process, in contrast, the total amount of air supplied to the pressure column, and in particular the total amount of air supplied to the rectification column system as a whole, is compressed to a pressure in a pressure range that is significantly higher than the pressure range at which the pressure column is operated. Such a pressure range may, for example, be between 8 and 100 bar. The air fed into the pressure column is therefore expanded in a high-pressure process before being fed into pressure column. High-pressure processes have been described at various places and are known from EP 2 980 514 A1 and EP 2 963 367 A1, for example.

[0008] While main air compressor/booster air compressor processes are typically considered more energy-efficient as compared to high air pressure processes, the latter may, due to the fact that they do not comprise booster air compressors but use a single machine for air compression, allow for constructing air separation units with reduced capital expenses and maintenance costs.

[0009] There is a desire for improvements in high air pressure processes for cryogenic separation of air including lower energy consumption and costs which at least partly realize the same, or an improved, energy efficiency as main air compressor/booster air compressor processes.

Summary

[0010] Against this background, the present invention proposes a process for the cryogenic separation of air and a corresponding plant comprising the features of the independent claims. Preferred embodiments of the present invention are the subject of the dependent claims and the description that follows.

[0011] The method as proposed herein is particularly suitable for producing gaseous oxygen at a pressure from 4 to 10 bar as a main product, wherein the term "main product" is particularly used to express that further air products, besides the main product are, in total, produced in a smaller amount than the main product, and particularly in an amount corresponding to not more than 50%, 25%, or 10% of the main product. In the following, before turning again to the specific features and advantages of the present invention and its embodiments, some basic principles of the present invention are explained and terms used to describe the invention are defined.

[0012] For more information relating to the devices and apparatus used in air separation units, reference is made to technical literature such as Häring (see above), especially Section 2.2.5.6, "Apparatus". In the following, some aspects of such devices are explained in more detail for clarification and clearer differentiation.

[0013] In air separation processes and plants, multistage turbo compressors are used to compress all the air to be separated, such compressors being referred to as "main air compressors" or "main compressors" for short. The mechanical design of turbocompressors is basically known to the skilled person. In a turbocompressor, the medium to be compressed is pressurized by means of turbine blades or impellers, which are arranged on a turbine wheel or directly on a shaft. A turbocompressor forms a structural unit, but in a multi-stage turbocompressor this can comprise several compressor stages. A compressor stage usually comprises a turbine wheel or a corresponding arrangement of turbine blades. All these compressor stages can be driven by a common shaft. However, it may also be intended to drive the compressor stages in groups with different shafts, wherein the shafts may also be connected to each other via gearboxes to rotate at different speeds.

[0014] The main air compressor is characterized by the fact that it compresses the entire quantity of air fed into the column system which is separated for the production of air products, i.e. the entire feed air. Accordingly, a "booster air compressor" or "post compressor" can also be provided, in which, however, only a part of the air volume compressed in the main air compressor is brought to an even higher pressure. This can also be a turbocompressor. For the compression of partial air volumes, further turbocompressors are typically provided, also referred to as boosters, but in comparison to the main air compressor or the booster air compressor, such further turbocompressors only compress air to a relatively small extent. A booster air compressor may also be present in a high-pressure air process where it compresses a partial air volume starting from a high pressure provided by the main air compressor. A booster is referred to as being a "warm booster" if it is supplied with an air feed at a temperature typically above 273 K, particularly above 280 K or above 300 K, and up to 350 K. In contrast, a booster is referred to as being a "cold booster" if it is supplied with an air feed at a temperature typically below 273 K, particularly below 260 K, below 250 K or below 200 K and particularly down to 150 K or less, more specific values used in an embodiment proposed herein being explained below.

[0015] Air can also be expanded at several points in air separation units, for which purpose expansion machines in the form of turboexpanders can be used. Turboexpanders can also be coupled to and drive turbocompressors. Turboexpanders are also referred to as "expansion turbines", or for short "turbines" or "expanders" hereinbelow, these terms being used synonymously. If one or more turbocompressors are driven without externally supplied energy, i.e. via one or more turboexpanders, the term "turbine booster" or "booster turbine" is also used for such an arrangement. In a turbine booster, the turboexpander or expansion turbine and the turbocompressor or booster are mechanically coupled, wherein the coupling can be such as to result in the same speed, e.g. via a common shaft, or in different speeds, e.g. via an interposed gearbox. A turbine booster or booster turbine may also include further braking means such as oil brakes, electric generators and the like.

[0016] In typical air separation units, appropriate expansion turbines are available at different locations for cooling and sometimes liquefaction of fluid streams. These are in particular so-called Joule-Thomson turbines, Claude turbines and Lachmann turbines. For the function and purpose of some of these turbines, reference is made to technical literature as well, for example to F.G. Kerry, Industrial Gas Handbook: Gas Separation and Purification, CRC Press, 2006, especially sections 2.4, "Contemporary Liquefaction Cycles", 2.6, "Theoretical Analysis of the Claude Cycle" and 3.8.1, "The Lachmann Principle". The present invention makes use of a Lachmann turbine and a Claude turbine, the latter being referred to as "medium-pressure turbine" hereinbelow, wherein expanded in this turbine is thereafter at least partly introduced in the pressure column of the rectification column system.

[0017] Lachmann turbines are used since many years to increase the efficiency of air separation plants. For normal gaseous oxygen plants, 20% to 25% of the process air may be passed through one or more Lachmann turbines at almost its dew point and may then be passed into the low-pressure column at a point which may be just below the entrance of the rich liquid. This operation produces an oxygen product of slightly lower purity and saves energy. Hereinbelow, the term Lachmann turbine shall generally describe a turbine which expands air from a pressure generated by the main air compressor into the low-pressure column, and the term Lachmann air shall refer to air expanded in a Lachmann turbine.

[0018] Generally, the term "air product", in the language used herein, shall refer to a fluid in liquid or gaseous state in which a content of at least one air component such as nitrogen, oxygen, or a noble gas of atmospheric air is higher than in atmospheric air. An air product may be an essentially pure air component, "essentially pure" meaning a content of at least 90%, 95% or 99%. Such an air product may be herein be referred to by using the name of the main component ("oxygen", "nitrogen", etc.) only, even if minor amounts of one or more other components are present therein. A "liquid product" is an air product which is withdrawn from the air separation unit in liquid state and not evaporated therein, other than internally compressed air products which are initially produced in liquid state and thereafter evaporated or which are withdrawn from the column system already in gaseous state ("gas products").

[0019] For certain product requirements, such as 18.000 Nm^3/h (standard cubic meters per hour) gaseous oxygen (GOX) at 4.5 bar absolute pressure and at 99.5% purity, a high air pressure process which includes two turbines, i.e. a Lachmann turbine (also referred to as low-pressure or upper column turbine) and a cold booster turbine (also referred to as medium-pressure, lower column turbine, or Claude turbine) may be used.

[0020] When comparing a high air pressure process and a main air compressor/booster air compressor process, such as explained in more detail in connection with the preferred embodiments below, it can be seen that the high air pressure process is having disadvantages regarding power consumption. The process proposed herein overcomes this and may result in the same or better power characteristics than the main air compressor/booster air compressor process, such that the advantages of the high air pressure process do not anymore come with the drawback of lower energy efficiency.

[0021] The present invention and its embodiments are based on the finding that the feed temperature of the Lachmann air into the low-pressure column shall be as low as possible to gain in efficiency and argon recovery for the rectification. On the other hand, it was found that the turbine inlet temperature of the Lachmann turbine shall be as high as possible to have a higher power and refrigeration generation. For a standard process with fixed pressure, however, the Lachmann turbine inlet and outlet temperatures (the latter classically corresponding to the feed temperature into the low-pressure column) are fixed by the turbine efficiency.

[0022] The proposed process now allows for decoupling the low-pressure column feed temperature from the inlet and outlet temperatures of the Lachmann turbine. In this connection, it is proposed to use the main heat exchanger and/or the subcooler for cooling of the outlet stream of the Lachmann turbine. An aspect of the present invention relates to the use of a cold booster in connection with such an arrangement, such a cold booster being particularly driven by the Lachmann turbine or a medium pressure turbine as explained above, and the Lachmann turbine and the medium pressure turbine particularly being the only turbines in the system.

[0023] Herein, therefore, a method of cryogenic air separation using an air separation unit comprising a main air compressor, a main heat exchanger, a Lachmann turbine, a medium pressure turbine, a cold booster mechanically coupled to either the medium pressure turbine or Lachmann turbine, and a rectification column system including a pressure column and a low-pressure column is proposed, wherein at least 90% or (essentially) all of a total quantity of air supplied to the rectification column system and rectified therein is passed through the main air compressor and is compressed therein to a pressure level which is at least 2 bar, for example at least 4 bar, 6 bar, 8 bar or 10 bar and for example up to 100 bar, above an operating pressure level of the pressure column. The present invention, therefore, relates to a high air pressure process as described at the outset, and the outlet pressure of the main air compressor is particularly in a range from 6 to 10 bar, for example from 7 to 9 bar or specifically at about 8.5 bar absolute pressure.

[0024] In the proposed method, a first part of the total air quantity is, after the compression in the main air compressor, subjected, as Lachmann air, to a turboexpansion in the Lachmann turbine and is injected into the low-pressure column, as typical for Lachmann processes.

[0025] A second part of the total air quantity is, after the compression in the main air compressor, cooled in the main heat exchanger, thereafter subjected to a turboexpansion in the medium pressure turbine, and thereafter injected into the rectification column system, while a third part of the total air quantity is, after the compression in the main air compressor, cooled in the main heat exchanger, thereafter subjected to a compression in the cold booster, and therafter injected into the rectification column system.

[0026] As proposed herein, the Lachmann air is subjected to a post-expansion cooling step after its expansion in the Lachmann turbine and before its injection into the low-pressure column. This decouples, as mentioned, the outlet temperature from (and the inlet temperature to) the Lachmann turbine from the feed temperature into the low-pressure column, resulting in the advantages mentioned before and further below.

[0027] Using a post-expansion cooling step, the inlet temperature of the Lachmann turbine can be set higher, leading to higher refrigeration/power generation of the Lachmann turbine. Specific figures will be given below in connection with the description of preferred embodiments of the invention.

[0028] In the method proposed herein, the third part of the total air quantity is delivered to the cold booster at a temperature level of 105 to 130 K, representing the temperature range to which the third part of the total air quantity is cooled, particulary in the main heat exchanger, and an inlet temperature the cold booster is operated.

[0029] In certain embodiments, no further air besides the first and second part of the total air quantity is turboexpanded. This represents a difference from methods of the prior art where further turbines are used, particularly to produce large amounts of liquid air products for which additional cold needs to be generated. Such embodiments allow for constructing an air separation unit with less capital and operating expenses.

[0030] In certain embodiments, outlet streams of the Lachmann turbine and of the medium pressure turbine are provided in an at at least partly gaseous state. Particularly, such streams may comprise, by mass or volume, a proportion of more than 50, 60, 70, 80 or 90% gas, or they may be provided in an essentially or completely gaseous state.

[0031] According to embodiments the present invention, a temperature of the first part of the total air quantity, i.e., the Lachmann air, may be reduced from a temperature in a range from 112 to 125 K, e.g. from about 122 K, to a temperature in a range from 95 to 100 K, e.g. to about 97 K, in the post-expansion cooling step. The temperature may, in this case, or independently from the ranges indicated, be reduced by at least 12 K in certain embodiments. That means that the Lachmann turbine can operate at a higher temperature with higher cold generation.

[0032] Embodiments of the present invention include that the first part of the total air quantity, i.e., the Lachmann air, is subjected to a pre-expansion cooling step before its expansion in the Lachmann turbine, wherein a temperature of the first part of the total air quantity is reduced to a temperature in a range from 170 to 220 K, e.g. to about 189 K, in the pre-expansion cooling step. This contributes to a higher inlet temperature than in standard high air pressure processes.

[0033] The injection of the first part of the total air quantity, i.e., the Lachmann air, into the low-pressure column may be performed at a position at which an operating temperature thereof, i.e. of the low-pressure column, is in a range from 80 to 90 K, e.g. about 84 K, and the injection into the first part of the total air quantity according to embodiments of the present invention does advantageously not introduce excessive heat here.

[0034] In embodiments of the present invention, the post-expansion cooling step is performed using the main heat exchanger and/or using a subcooler or the air separation unit. This enables an efficient use of the apparatus installed in an air separation unit.

[0035] The Lachmann turbine or the medium pressure turbine and the cold booster are mechanically coupled, as mentioned above, as generally known for a in a turbine booster to recover work freed by expansion. The other turbine not coupled in such a way may also be coupled with a booster or an electric generator.

[0036] The present invention was found particularly suitable to produce gaseous oxygen at a pressure level of 4 to 8 bar and at a purity of 96.0 to 99.9%, e.g. about 99.5%, oxygen content, thus effectively fulfilling the need of certain consumers.

[0037] The proposed air separation unit comprising a main air compressor, a main heat exchanger, a Lachmann turbine, a cold booster mechanically coupled to a medium pressure turbine, and a rectification column system including a pressure column and a low-pressure column, is configured to compress at least 90% of a total quantity of air supplied to the rectification column system in the main air compressor to a pressure level which is at least 2 bar above an operating pressure level of the pressure column, and to subject a first part of the total air quantity compressed in the main air compressor thereafter, as Lachmann air, to a turboexpansion in the Lachmann turbine and to inject the same into the low-pressure column. The proposed air separation unit is configured to cool a second part of the total air quantity, after the compression in the main air compressor, in the main heat exchanger and to thereafter subject the same to a turboexpansion in the medium pressure turbine, and thereafter to inject it into the rectification column system. The proposed air separation unit is further configured to cool a third part of the total air quantity, after the compression in the main air compressor, in the main heat exchanger, thereafter subject the same to a compression in the cold booster, and thereafter inject it into the rectification column system. The proposed air separation unit is also configured to subject the first part of the total air quantity to a post-expansion cooling step after its expansion in the Lachmann turbine and before its injection into the low-pressure column.

[0038] As to specific further features and embodiments of such an air separation unit, reference is made to the explanations above relating to the method according to the invention and its advantageous embodiments. This equally applies for a corresponding apparatus which is adapted to perform a corresponding method or one of its embodiments. Such an apparatus may particularly include a control unit programmed or adapted to control the apparatus accordingly.

Short description of the Figures

[0039] Embodiments of the invention will now be described, by way of example only, with reference to accompanying drawings, in which

Figure 1 schematically illustrates an air separation unit not being part of the invention;

Figure 2 shows a temperature-heat content diagram for an air separation process not forming part of the present invention;

Figure 3 shows a temperature-heat content diagram for an air separation process not forming part of the present invention;

Figure 4 schematically illustrates an air separation unit according to an embodiment of the present invention;

Figure 5 shows a temperature-heat content diagram for an air separation process according to an embodiment of the present invention; and

Figure 6 schematically illustrates an air separation unit according to an embodiment of the present inventionin a partial view.

Embodiments of the invention

[0040] In the Figures, elements of identical, essentially identical, functionally comparable, or technically compatible function and/or purpose and/or construction may be identified with identical reference numerals, and repeated explanations may be omitted for reasons of conciseness. Explanations herein relating to devices, apparatus, arrangements, systems, etc., according to embodiments of the present invention likewise may apply to methods, processes, procedures, etc. according to embodiments of the present invention and vice versa.

[0041] The various embodiments described herein are presented only to assist in understanding and teaching the claimed features. These embodiments are provided as a representative sample of embodiments only, and are not exhaustive and/or exclusive. It is to be understood that advantages, embodiments, examples, functions, features, structures, and/or other aspects described herein are not to be considered limitations on the scope of the invention as defined by the claims or limitations on equivalents to the claims, and that other embodiments may be utilised and modifications may be made without departing from the scope of the claimed invention. Various embodiments of the invention may suitably comprise, consist of, or consist essentially of, appropriate combinations of the disclosed elements, components, features, parts, steps, means, etc., other than those specifically described herein. In addition, this disclosure may include other inventions not presently claimed, but which may be claimed in future, particularly when encompassed by the scope of the independent claims.

[0042] Figure 1 schematically illustrates an air separation unit not being part of the invention. The air separation unit shown in Figure 1 is configured to perform a high air pressure process in which a main air compressor 1 in a "warm" part of the air separation unit, which is not illustrated in detail, is configured to compress essentially the whole air processed in the air separation unit and supplied to a rectification column system 10 to a pressure level which is at least 2 bar above an operating pressure level of a pressure column 11 of the rectification column system, forming a feed air stream a. In an example, this pressure may be about 8.5 bar absolute pressure. Further components form also part of the warm part, such as a pre-purification unit, but are not illustrated for reasons of conciseness and because they are known to the skilled person.

[0043] A partial stream b of feed air stream a is cooled in a main heat exchanger 2 and withdrawn therefrom at a temperature of e.g. about 161 K. Partial stream b is expanded in a Lachmann turbine 3, which is coupled to an electric generator G, to a pressure in a range at which a low-pressure column 12 of the rectification column system 10 is operated. The expanded partial stream, still referred to with b, is injected into the low-pressure column 12 at a temperature of e.g. about 104 K at an injection position at which an operating temperature of the low-pressure column 12 is about 84 K.

[0044] A further partial stream c of feed air stream a is also injected into the main heat exchanger 2. A part thereof is, as an air stream d, withdrawn from the main heat exchanger 2 at an intermediate temperature and expanded in a medium pressure turbine 4 which is coupled to a booster 5. This air stream d is, after said expansion, injected into a phase separator 6 in which a liquid phase and a gaseous phase are separated from each other. A liquid stream e withdrawn from phase separator 6 is combined with a liquid stream f from the pressure column 11 cooled in a subcooler 7 and is thereafter injected to into the low-pressure column 12. A gaseous stream g withdrawn from phase separator 6 is injected into the pressure column 11.

[0045] A further part of partial stream c is, as an air stream h, also withdrawn from the main heat exchanger 2, but at a lower temperature than air stream d, and is further compressed in booster 5, before being in one part recombined with partial stream c and in a further part, as an air stream l, at least partly liquefied in main heat exchanger 2. A yet further partial stream k of feed air stream a is also at least partly liquefied in main heat exchanger 2. Streams l and k are combined and after their combination injected into the pressure column 11.

[0046] The further operation of the air separation unit shown in Figure 1 may correspond to known air separation units and is therefore not explained in detail. As air products, a pressurized liquid nitrogen stream s, liquid oxygen t, unpressurized liquid nitrogen u, internally compressed oxygen v, internally compressed nitrogen r, and liquid argon x may, among others, be provided. A stream labelled y is indicated to demonstrate its interconnection. Internal compression pumps 8, 9 are provided.

[0047] As mentioned above, there is, as recognized according to embodiments of the present invention, room for improvement in an air separation unit as shown in Figure 1. This is now explained in connection with Figures 2 and 3 which show temperature-heat content (Q-T) diagrams for a main air compressor/booster air compressor process (the diagram of Figure 2) on the one hand and for a standard high air pressure process as shown in Figure 1 (the diagram of Figure 3). In both cases, a temperature in K is indicated on the vertical axis and an enthalpy sum in KW is indicated on the horizontal axis. The upper lines indicates the sum curve of the hot stream, the lower line indicates the sum curve of the cold streams.

[0048] The graph in Figure 3 is, in other words, representing the heat profile for the given high air pressure solution of Figure 1. The graph in Figure 2 represents the main air compressor/booster air compressor solution. It can be seen that especially in the cold part the high air pressure process is having power disadvantages. This is leading to approximately 150 KW power difference compared to a main air compressor/booster air compressor process.

[0049] The present invention and its embodiments are, as mentioned before and only briefly repeated now, based on the finding that the feed temperature into the low-pressure column shall be as low as possible to gain in efficiency and argon recovery for the rectification. On the other hand, it was found that the turbine inlet temperature shall be as high as possible to have a higher power and refrigeration generation. For a standard process with fixed pressure, however, turbine inlet and outlet temperatures (the latter classically corresponding to the feed temperature into the low-pressure column) are fixed by the turbine efficiency.

[0050] The proposed process now allows for decoupling the low-pressure column feed temperature from the inlet and outlet temperatures of the Lachmann turbine. In this connection, it is proposed to use the main heat exchanger and/or the subcooler for cooling of the outlet stream of the Lachmann turbine.

[0051] In other words, the solution of embodiments of the present invention includes that, using a cooling step, the inlet temperature of the Lachmann turbine may be set higher, leading to higher refrigeration/power generation of the Lachmann turbine.

[0052] Figure 4 schematically illustrates an air separation unit 100 according to an embodiment of the present invention. Only those features differing from the non-inventive air separation unit shown in Figure 1 are explained below.

[0053] A partial stream of feed air stream a, which is indicated with b here as well, is cooled in the main heat exchanger 2 and withdrawn therefrom, but in contrast to the air separation unit shown in Figure 1 at a significantly higher temperature, e.g. at a temperature of about 189 K. This cooling step is referred to as pre-expansion cooling step herein. Partial stream b is, like in the air separation unit shown in Figure 1, expanded in a Lachmann turbine 3, which is coupled to an electric generator G, to a pressure in a range at which a low-pressure column 12 of the rectification column system 10 is operated. The expanded partial stream, still referred to with b, leaves the Lachmann turbine 3 at a temperature which is also higher than in the air separation unit shown in Figure 1, e.g. at a temperature of about 122 K. Stream b is then further cooled to a temperature of e.g. 97 K. This cooling step is referred to as post-expansion cooling step herein. This cooling step can be performed, as shown, in the main heat exchanger 2 only, but also (additionally or alternatively) in subcooler 7. Stream b is injected into the low-pressure column 12 at a temperature of e.g. about 104 K at an injection position at which an operating temperature of the low-pressure column 12 is about 84 K. That is, the injection is performed at essentially the same temperature as in the air separation unit shown in Figure 1, but the inlet and outlet temperatures of the Lachmann turbine 3 are significantly higher, leading to the advantages explained.

[0054] Coming back to the non-inventive solution illustrated in Figure 1, representing a standard high air pressure process with cold booster, the Lachmann turbine 3 inlet temperature is at about 161 K and the Lachmann turbine outlet temperature is at about at 104 K. The expanded Lachmann stream b is fed to the low-pressure column 12. As per column temperature profile at about 84 K, stream b is approximately 20 K too warm when injected in this non-inventive solution into the low-pressure column 12, causing transportation of excess heat to the rectification column system 10 and an evaporation of liquid. Compared to a main air compressor/booster air compressor process (turbine inlet at about 156 K, outlet at about 98.6 K), the Lachmann turbine inlet temperature in a high air pressure process as illustrated for the air separation unit shown in Figure 1, and for a given mean temperature difference (MTD) of e.g. 5 K at the main heat exchanger 2 conventionally cannot further reduced.

[0055] For this mean temperature difference at the main heat exchanger (5 K), the turbine inlet temperature is at 189 K, turbine outlet temperature at 122 K and the cooled stream downstream the main heat exchanger at 97 K. The higher turbine inlet temperature (at same flow) is leading to an increase of refrigeration power by 20%. The low-pressure column feed temperature enhances the argon production by 0.4%. Total power consumption is improved by 1.2%.

[0056] These improvements are immediately evident from the temperature-heat content diagram as illustrated in Figure 5, for which essentially the same explanations as for the diagrams of Figures 2 and 3 apply, and which relates to an air separation unit 100 as illustrated in Figure 4 and a corresponding method.

[0057] Figure 6 shows a partial view of an air separation unit which is an alternative embodiment of the air separation unit shown in Figure 4. For reasons of generality, only the main heat exchanger 2 and certain streams, i.e. streams b, c, d, h and i, as well as the Lachmann turbine 3, the medium pressure turbine 4, the booster 5, and a generator G are shown. As illustrated, in the embodiment shown in Figure 6, the booster 5 is mechanically coupled with the Lachmann turbine 3 instead of the medium pressure turbine, and the medium pressure turbine is coupled with the generator G.

Claims

1. A method of cryogenic air separation using an air separation unit (100) comprising a main air compressor (1), a main heat exchanger (2), a Lachmann turbine (3), a medium pressure turbine (4), a cold booster (5) mechanically coupled to either the Lachmann turbine (3) or the medium pressure turbine (4), and a rectification column system (10) including a pressure column (11) and a low-pressure column (12), wherein

- at least 90% of a total air quantity supplied to the rectification column system (10) is compressed in the main air compressor (1) to a pressure level at least 2 bar above an operating pressure level of the pressure column (11),
- a first part of the total air quantity is, after the compression in the main air compressor (1), subjected to a turboexpansion in the Lachmann turbine (3) and is thereafter injected into the low-pressure column (12),
- a second part of the total air quantity is, after the compression in the main air compressor (1), cooled in the main heat exchanger (2), thereafter subjected to a turboexpansion in the medium pressure turbine (4), and thereafter injected into the rectification column system (10), and
- a third part of the total air quantity is, after the compression in the main air compressor (1), cooled in the main heat exchanger (2), thereafter subjected to a compression in the cold booster (5), and thereafter injected into the rectification column system (10), and

characterised in that

- the first part of the total air quantity is subjected to a post-expansion cooling step after its turboexpansion in the Lachmann turbine (3) and before its injection into the low-pressure column (12).

2. The method according to claim 1, wherein the third part of the total air quantity is delivered to the cold booster (5) at a temperature level of 108 to 120 K.

3. The method according to claim 1 or 2, wherein no further air besides the first and second part of the total air quantity is turboexpanded.

4. The method according to any one of the preceding claims, wherein outlet streams of the Lachmann turbine (3) and of the medium pressure turbine (4) are provided in an at at least partly gaseous state.

5. The method according to claim 1, wherein a temperature of the first part of the total air quantity is reduced from a temperature in a range from 110 to 130 K to a temperature in a range from 93 to 105 K, and/or by at least 10 K in the post-expansion cooling step.

3. The method according to claim 1 or 2, wherein the first part of the total air quantity is subjected to a pre-expansion cooling step before its expansion in the Lachmann turbine (3), wherein a temperature of the first part of the total air quantity is reduced to a temperature in a range from 170 to 220 K in the pre-expansion cooling step.

4. The method according to any of the preceding claims, wherein the injection of the first part of the total air quantity into the low-pressure column (12) is performed at a position at which an operating temperature thereof is in a range from 80 to 90 K.

5. The method according to any of the preceding claims, wherein the post-expansion cooling step is performed using the main heat exchanger (2) and/or using a subcooler (7) or the air separation unit (100).

6. The method according to any one of the preceding claims, wherein the first further part of the total air quantity compressed in the main air compressor (1) is partly liquefied by the expansion in the medium pressure turbine (4) and thereafter phase-separated in a phase separator (6), forming a liquid and a gaseous fraction

7. The method according to claim 8, wherein the liquid fraction is injected into the low-pressure column (12) and/or wherein the gaseous fraction is injected into the high-pressure column (11) after the phase separation.

8. The method according to any of the preceding claims, wherein the Lachmann turbine (3) or the medium pressure turbine (4) is mechanically coupled with a booster or a generator.

9. The method according to any one of the preceding claims, wherein the method is used to produce gaseous oxygen at a pressure level of 4 to 10 bar and at a purity of 96,0 to 99,99 percent oxygen content.

10. An air separation unit (100) comprising a main air compressor (1), a main heat exchanger (2), a Lachmann turbine (3), a medium pressure turbine (4), a cold booster (5) mechanically coupled to either the Lachmann turbine (3) or the medium pressure turbine (4) and a rectification column system (10) including a pressure column (11) and a low-pressure column (12), wherein the air separation unit (100) is configured to

- compress at least 90% of a total air quantity supplied to the rectification column system (10) in the main air compressor (1) to a pressure level which is at least 2 bar above an operating pressure level of the pressure column (11),
- to subject a first part of the total air quantity, after the compression in the main air compressor (1), to a turboexpansion in the Lachmann turbine (3) and injected it into the low-pressure column (12),
- to cool a second part of the total air quantity, after the compression in the main air compressor (1), in the main heat exchanger (2), thereafter subjected the same to a turboexpansion in the medium pressure turbine (4), and thereafter injected it into the rectification column system (10), and
- to cool a third part of the total air quantity, after the compression in the main air compressor (1), in the main heat exchanger (2), thereafter subjected the same to a compression in the cold booster (5), and thereafter inject it into the rectification column system (10),

characterised in that the air separation unit (100) is configured to

- subject the first part of the total air quantity to a post-expansion cooling step after its expansion in the Lachmann turbine (3) and before its injection into the low-pressure column (12).

11. The air separation unit (100) according to claim 10 adapted to perform a method according to any one of claims 1 to 9.

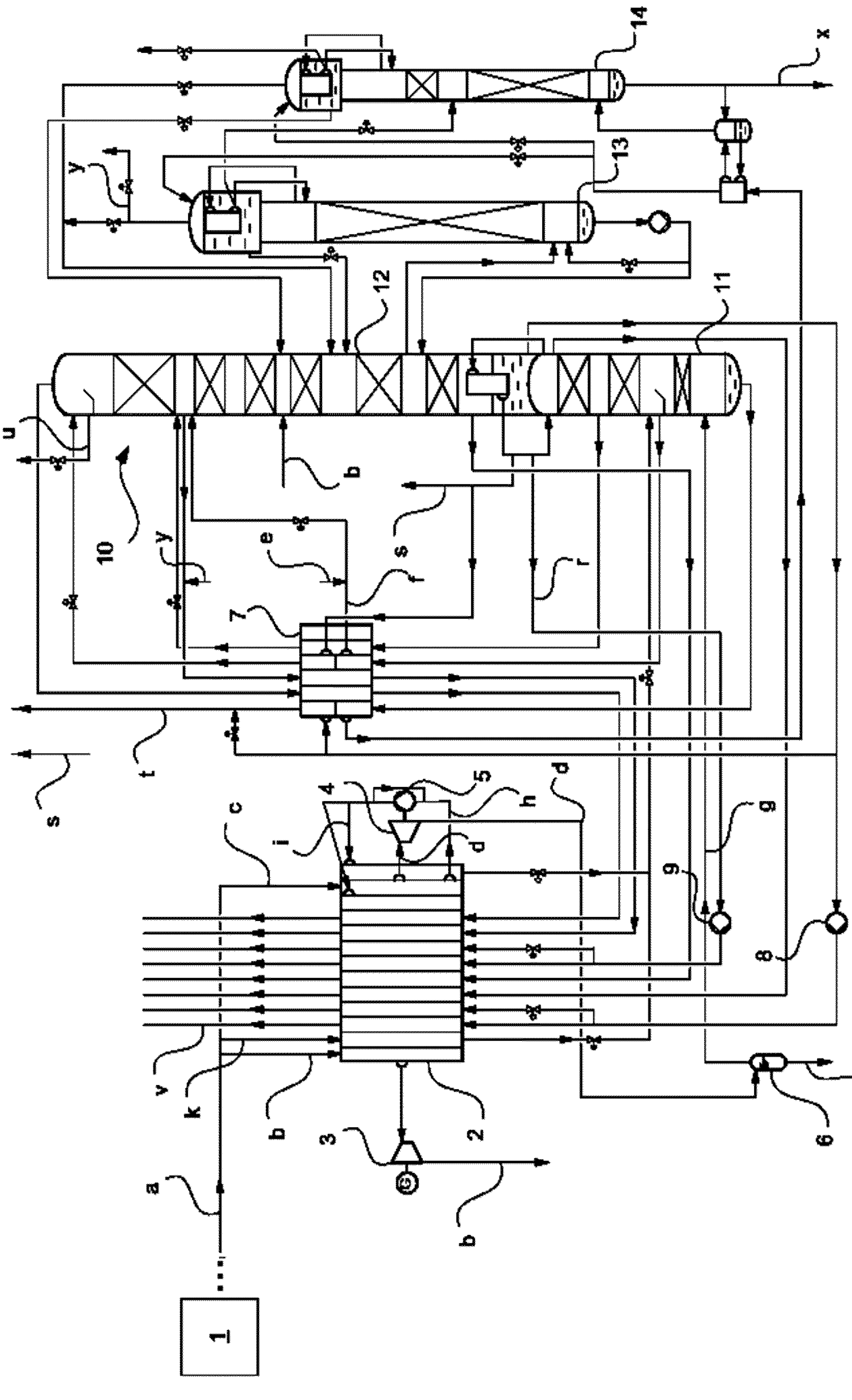

Fig. 1

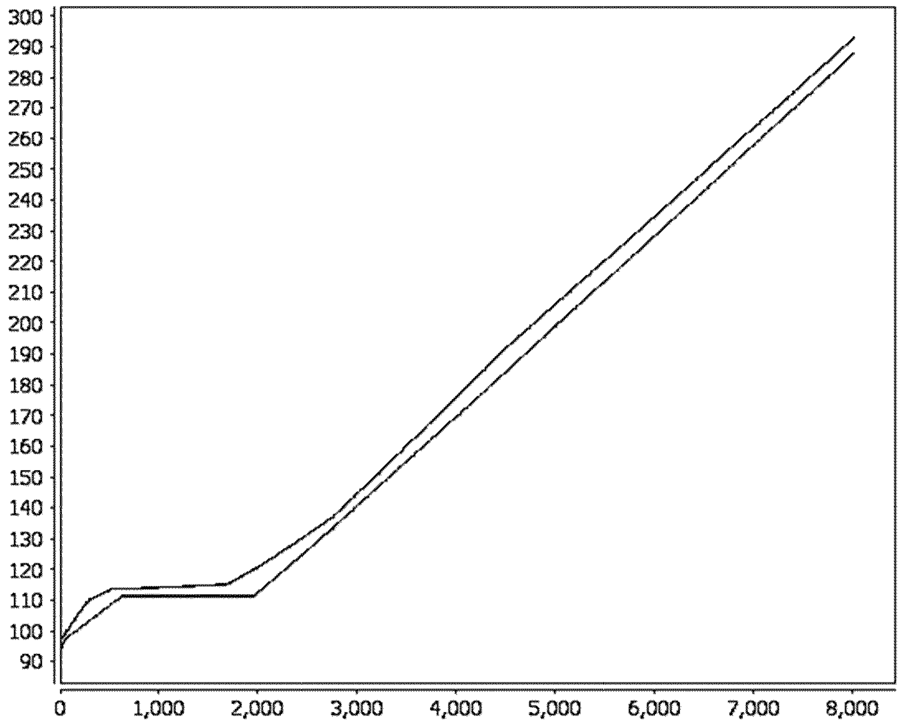
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Fig. 2

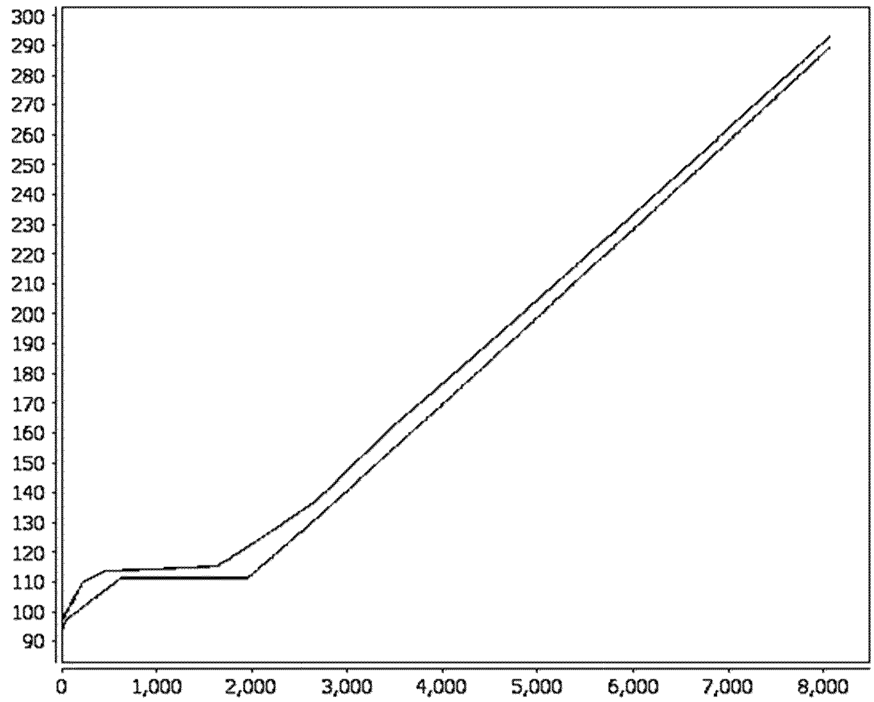
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Fig. 3

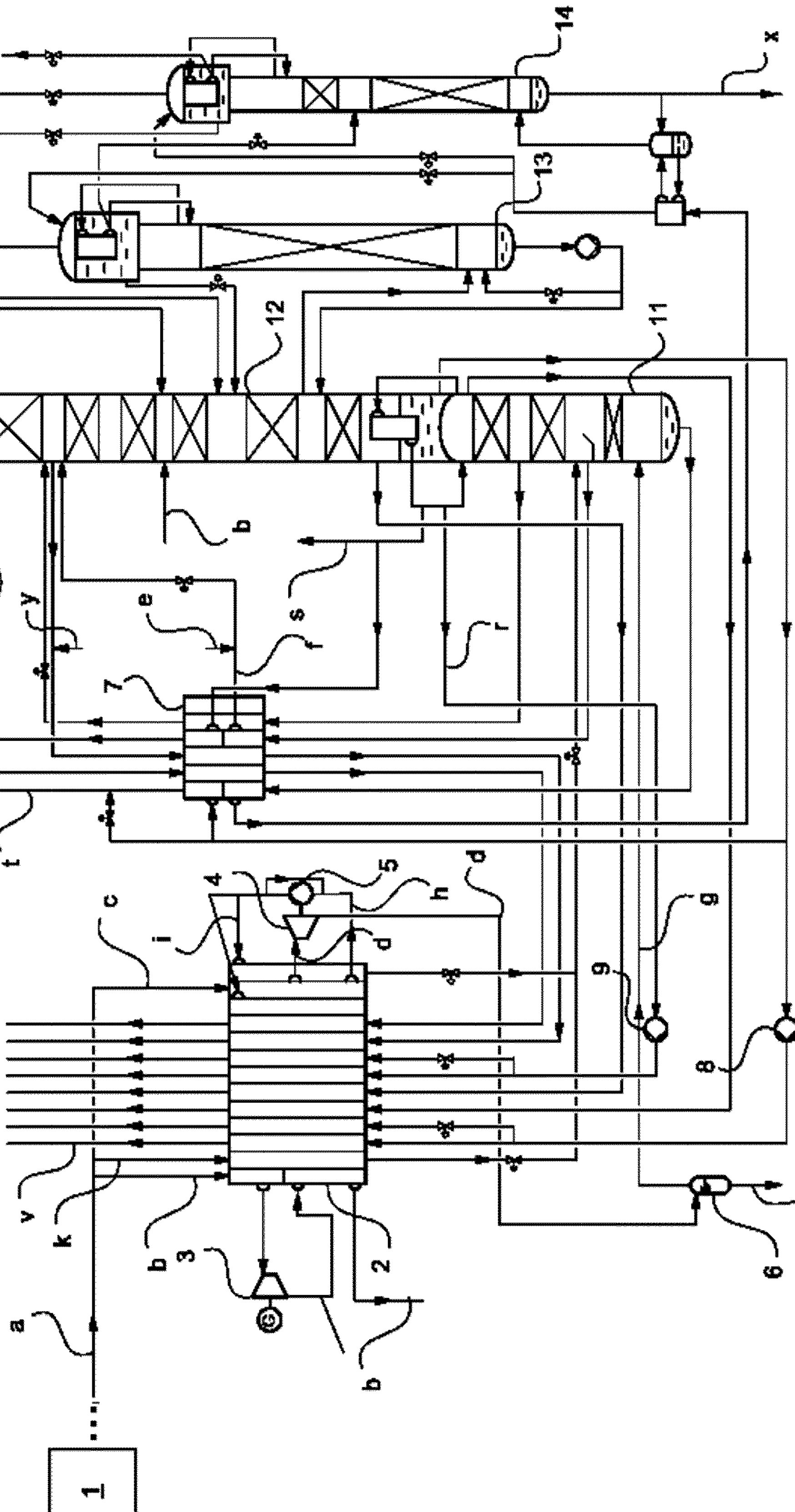

Fig. 4

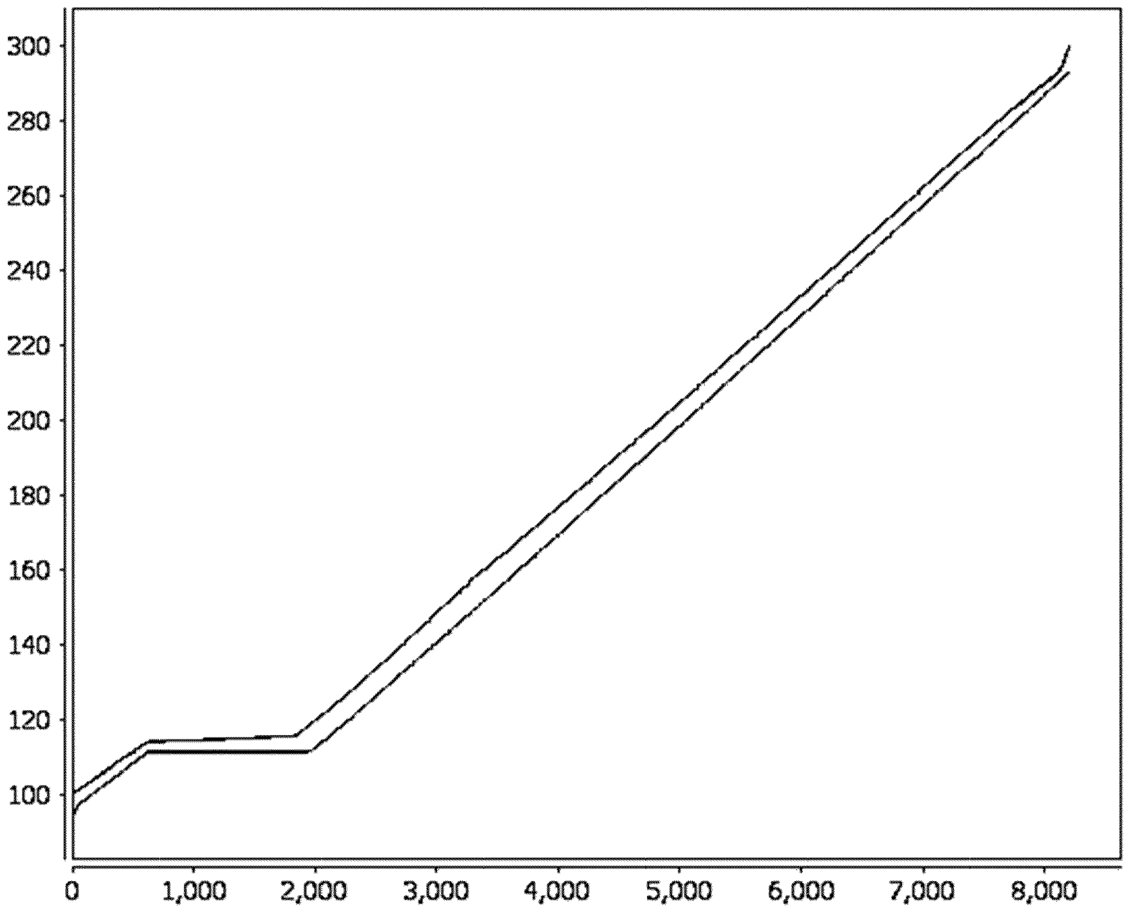
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Fig. 5

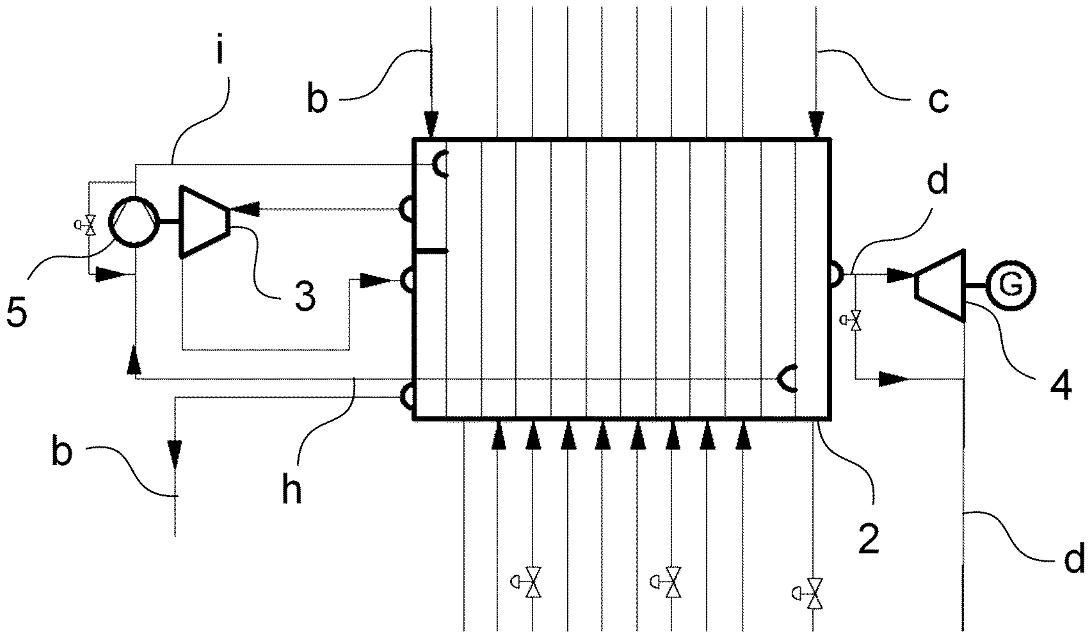

Fig. 6

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Application Number
EP 23 02 0437

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Place of search	Date of completion of the search	Examiner
Munich	16 February 2024	Göritz, Dirk

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