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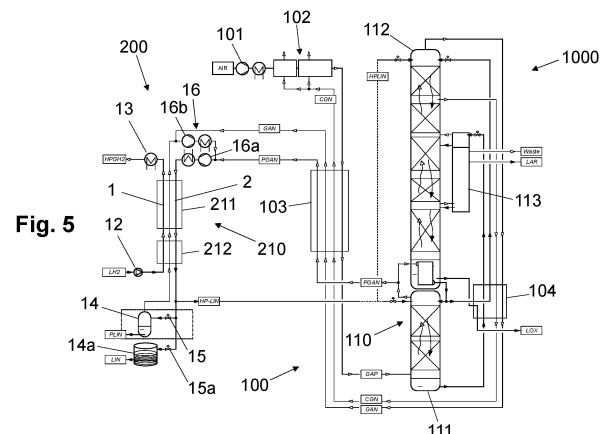
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(54) METHOD AND APPARATUS FOR PROVIDING LIQUID AIR PRODUCTS

(57) A method for providing air products (LIN, PLIN, LOX, LAR) is proposed, said method including cryogenically separating air in an air separation unit (100), with-drawing gaseous nitrogen (GAN, PGAN) from the air separation unit (100), compressing the gaseous nitrogen (GAN, PGAN) withdrawn from the air separation unit (100) to a liquefaction pressure level, passing the gaseous nitrogen (GAN, PGAN) at the liquefaction pressure level through a heat transfer system (210) to form pressurized liquid nitrogen (HP-LIN) at the liquefaction pressure level, expanding a first part of the pressurized liquid nitrogen (HP-LIN) from the liquefaction pressure level to a rectification pressure level, introducing the first part of the liquid nitrogen expanded to the rectification pressure level into the air separation unit (100), expanding one or more further parts of the liquid nitrogen from the liquefaction pressure level (HP-LIN) to one or more storage pressure levels, and introducing the one or more further parts of the liquid nitrogen (PLIN, LIN) expanded to the one or more storage pressure levels into one or more storage units (14, 14a), wherein the method includes converting liquid hydrogen (LH2) to form pressurized gaseous hydrogen (HPGH2) including pressurizing the liquid hydrogen (LH2) to an evaporation pressure level, and evaporating the liquid hydrogen (LH2) in the heat transfer system (210) at the evaporation pressure level. A corresponding apparatus (1000) is also proposed herein.



Description

[0001] The invention relates to a method and an apparatus for or providing liquid air products.

Background

[0002] The production of air products in liquid or gaseous state by cryogenic separation of air in air separation plants (air separation units) 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] Air separation units can be configured differently depending on the air products to be supplied and their required aggregate and pressure conditions. Particularly air separation units for production of liquid air products have a complex morphology. Usually, this sort of air separation units does not only comprise the basic equipment for air separation including a main air compressor with air cooling and air purification, a main heat exchanger, and a rectification column system, but some additional units adapted for an integrated refrigeration process and equipment for generation of large cooling power or capacity required for liquefaction of air gases.

[0004] In terms of hardware components, such additional units may include a recycle compressor, a warm expander/booster unit and a cold expander/booster unit integrated with the basic air separation process via the main heat exchanger. The latter may therefore be required to be very large. Additional process equipment for boosting the rectification performance of the rectification column system may also be present. An additional rectification column or an additional (integrated or external) cycle/loop driven by a compressor (cold or warm) may be present in an air separation unit for production of liquid air products, to which the present disclosure particularly relates.

Summary

[0005] Against this background, a method for or providing liquid air products and a corresponding apparatus are proposed. Embodiments are the subject matter of the dependent claims and of the description that follows hereinbelow.

[0006] The method for or providing air products as proposed herein includes cryogenically separating air in an air separation unit, withdrawing gaseous nitrogen from the air separation unit, compressing the gaseous nitrogen withdrawn from the air separation unit to a liquefaction pressure level, passing the gaseous nitrogen at the liquefaction pressure level through a heat transfer system to form pressurized liquid nitrogen at the liquefaction pressure level, expanding a first part of the pressurized liquid nitrogen from the liquefaction pressure level to a rectification pressure level, introducing the first part of the liquid nitrogen expanded to the rectification

pressure level into the air separation unit, expanding one or more further parts of the liquid nitrogen from the liquefaction pressure level to one or more storage pressure levels, and introducing the one or more further parts of the liquid nitrogen expanded to the one or more storage pressure levels into one or more storage units.

[0007] In the method proposed herein, liquid hydrogen is subjected to a conversion to form pressurized gaseous hydrogen, wherein the conversion includes pressurizing the liquid hydrogen to an evaporation pressure level, and evaporating the liquid hydrogen in the heat transfer system at the evaporation pressure level.

[0008] Using the proposed method, liquid nitrogen from an air separation process and system for production of liquid products can be provided with considerably lower capital and lower operating expenses in comparison to state-of-the-art processes. A very easy version of a basic air separation process with liquid nitrogen injection may be combined, as proposed herein, with an external nitrogen liquefaction unit utilizing cold from evaporating liquid hydrogen for nitrogen liquefaction. The liquid nitrogen produced in the external nitrogen liquefaction unit is injected into the rectification system or a corresponding cold box for driving the rectification and the production of liquid air products, particularly liquid oxygen and liquid argon, in the air separation unit.

[0009] Generally, the term "liquid air product", in the language used herein, shall refer to a fluid in liquid state in which a content of at least one air component (nitrogen, oxygen, noble gas) of atmospheric air is the same or higher than in atmospheric air. A liquid 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 ("nitrogen", "oxygen", "argon", etc.) only, even if minor amounts of one or more other components are present in the air product. Also liquefied air is a liquid air product as understood herein. A liquid air product is an air product which is withdrawn from the air separation unit, more precisely in a rectification column system, i.e., particularly a pressure column, a low-pressure column, an argon column of any kind or a further rectification column, in liquid state and not evaporated therein, other than internally compressed air products which are initially produced in liquid state and thereafter evaporated ("gas products") or which are withdrawn from the column system already in gaseous state.

[0010] An air separation process and system for production of liquid products with reduced capital expenses (by 40 to 50%) and reduced operating expenses (by 60 to 70%) is proposed herein. The air separation process is considerably simplified, and it particularly does not comprise any recycles, expanders, and recycle compressors. The number of columns and condensers may be minimized. The external nitrogen liquefaction unit provided in certain embodiments is considerably simplified as well. It comprises a compact heat exchanger system and nitrogen compressor, but the flow rate is reduced to the

nitrogen product amount.

[0011] The proposed process may particularly be based on a conventional air separation process for production of gaseous air products, which may in particular include pressurized gaseous nitrogen (PGAN) and (essentially unpressurized) gaseous nitrogen (GAN). Both these products are, as proposed in certain embodiments herein, particularly compressed to supercritical pressure by means of nitrogen compressors, and liquefied by cold pressurized liquid hydrogen by means of a separate heat transfer system (including in particular two heat transfer units).

[0012] Liquid nitrogen (LIN) may be collected as a more or less pressure-less liquid nitrogen product collected in flat bottom tanks, or/and pressurized liquid nitrogen (PLIN) may be collected at a higher pressure in in bullet-type tanks in certain embodiments. These are the "one or more further parts" of the liquid nitrogen referred to hereinbefore. A fraction of liquefied cold nitrogen (HP-LIN), the "first part of the liquid nitrogen" as referred to above, is returned to the rectification column system of the air separation unit. It may particularly be injected at the top of the pressure column or/and at the top of the low-pressure column. The flow rate of this material stream is particularly sufficient, or selected to be sufficient, for driving rectification processes inside of the rectification column system, and production of liquid oxygen (LOX), liquid argon (LAR, if required), liquid air (LAIR, if required), a crude Krypton/Xenon product (if required), a crude Helium/Neon product (if required), and to compensate heat inleaks through thermal insulation, heat bridges and other similar items.

[0013] The main air separation process may be reduced to a minimalistic version. It may comprise or consist of the main air compressor with air cooling and air purification, the main heat exchanger and, in certain embodiments, an essentially conventional rectification column system. It particularly does not comprise any further rotating machinery like expander units and a recycle compressor. The main heat exchanger may be configured as a very compact low-pressure heat exchanger, since no recycled material streams are managed there.

[0014] In certain embodiments, the heat transfer system comprises a first heat transfer unit and a second heat transfer unit, wherein said passing the gaseous nitrogen at the liquefaction pressure level through the heat transfer system to form pressurized liquid nitrogen at the liquefaction pressure level includes first passing the gaseous nitrogen at the liquefaction pressure level through the first heat transfer unit and thereafter through the second heat transfer unit. In these embodiments, said evaporating the liquid hydrogen in the heat transfer system at the evaporation pressure level may particularly include passing the liquid hydrogen either cocurrently (in the same flow direction) or countercurrently (in an opposite flow direction) to the gaseous nitrogen through the second heat transfer unit and thereafter passing the

liquid hydrogen countercurrently to the gaseous nitrogen through the first heat transfer unit.

[0015] Said embodiments may particularly solve problems resulting from the still very cold liquid hydrogen after pressurization. This temperature is usually lower than 40 K, which is also lower than solidification temperature of the nitrogen at about 63 K. The risk that nitrogen solidifies inside of a heat exchanger (if cooled to temperatures below 63 K) is therefore, in conventional methods, considerably high. In case of nitrogen solidification, the corresponding channels of the heat exchanger will be blocked, an operation of this device is not secured. Usually, the system needs to be stopped in such cases for maintenance (warming-up, removal of solids etc.).

[0016] The embodiments including passing the liquid hydrogen cocurrently to the gaseous nitrogen through the second heat transfer unit make sure that the pressurized liquid hydrogen stream is not thermally contacted with the nitrogen stream at the liquefaction pressure level at the coldest temperature thereof, i.e. at the cold end of a single heat exchanger, but at a higher temperature. This becomes possible by the cocurrent operation of the second heat transfer unit. Therefore, the risk of solidification of nitrogen and a blockage of a heat exchanger or heat transfer unit is minimized. However, the present invention is not limited to a cocurrent operation of the second heat transfer unit, particularly if solidification of nitrogen can be avoided by other means, such as setting appropriate temperatures.

[0017] In the first heat transfer unit (which is operated at warmer temperatures), the hydrogen and the nitrogen are thermally contacted in a conventional way in certain embodiments, i.e., in a countercurrent flow. The nitrogen is cooled from ambient temperature level to an intermediate temperature level, the hydrogen is warmed up to a temperature close to the ambient temperature level.

[0018] In certain embodiments, heat transfer units and systems in the form of plate-fin heat exchangers, in particular brazed aluminium plate-fin heat exchangers (PFHE, see ISO 15547-2:3005) may be used. Characteristics of such heat exchangers are shown and described in particular in Figure 2 of ISO 15547-2:3005 and on page 5 of the publication "The Standards of the Brazed Aluminium Plate-Fin Heat Exchanger Manufacturers' Association" by ALPEMA, 3rd edition 2010.

[0019] Plate-fin heat exchangers can be used in a variety of process plants at a wide range of pressures and temperatures. They are used, for example, in the cryogenic separation of air, in the liquefaction of natural gas or in plants for the production of ethylene. If the term "heat exchanger", "heat transfer unit" or "heat transfer system" is used in the following, this can always refer to a brazed aluminium plate-fin heat exchanger or a system including such a heat exchanger. In particular, such a heat exchanger may be made of aluminium, where "aluminium" can also refer to an aluminium alloy.

[0020] In such heat exchangers, channels for the fluids

to be passed through the heat exchanger are formed by means of so-called fins, i.e. by means of structured metal sheets. Although these can be permeable, e.g. when using perforated plates, they define at least one preferred direction of the fluid flow and therefore represent fluid guiding devices. The fins or the structuring of corresponding sheets can be designed with different geometries, e.g. triangular, rectangular, wave-shaped, lamellar, perforated, toothed or with so-called staggered strip lamellas. The fins also keep the separator plates arranged between the respective plates of the plate heat exchanger at a distance. It is known, for example, that distributor and collector fins are used to distribute the injected fluid to the fins running in the central area of the plate heat exchanger, typically in a horizontal or vertical direction, or to collect it from them. Distributor and collector fins are fluid-connected to a feed header on the one hand and a collector header on the other. A feed header in the condensation passages of a condenser evaporator is a gas inlet, a collection header is a liquid outlet, even if in certain cases non-condensed gas is also withdrawn via the latter.

[0021] In certain embodiments disclosed herein, a plate-fin heat exchanger may not be usable or advantageous in all cases, e.g., in the case of the second heat transfer unit, particularly due to large temperature differences. In such cases, a spiral wound heat exchanger, sometimes also referred to as coil-wound heat exchanger, may be used.

[0022] Spiral wound heat exchangers are often used in natural gas liquefaction processes and are described, e.g., in H.-W. Häring (eds.), *Industrial Gases Processing*, Wiley-VCH, 2006, especially section 7.6, "Process of Natural Gas Treatment" at pages 234 and 235. In a spiral wound heat exchanger, a large number of heat exchanger tubes, sometimes several thousand, are wound onto a central core tube (mandrel). The manufacturing process of a spiral wound heat exchanger may be comparable to winding yarn onto a spool. In this way, huge heating surfaces of several tens of thousands of square metres can be accommodated in one apparatus. In the tubes, the streams to be cooled are arranged upwards. On the shell side, the cold flow, in the present case evaporating hydrogen, falls down, cooling all the tubes evenly.

[0023] Spiral wound heat exchangers are mechanically robust, but, for design reasons, typically only one shell stream can be routed against several tube streams. Plate-fin heat exchangers, in contrast, are much more flexible in terms of flow arrangement.

[0024] However, many parallel cores are required due to the limited core dimensions and plate-fin heat exchangers are also more sensitive to temperature differences due to the brazed metal connections.

[0025] If, herein, it is mentioned that a "stream", "nitrogen" or "hydrogen" is passed through a heat transfer unit, it comes without saying that such fluid may be passed through a heat transfer unit parallelly in the form of partial

streams, particularly in different heat exchanger plates. If a "heat transfer unit" is mentioned here, this may be a separate heat exchanger block or a "heat transfer unit" may be a certain section of a common block. Commonly, the heat transfer units are referred to as a "heat transfer system".

[0026] In certain embodiments, said withdrawing the gaseous nitrogen from the air separation unit may include withdrawing a first withdrawal stream of gaseous nitrogen at a first withdrawal pressure level below the liquefaction pressure level from the air separation unit and further may include withdrawing a second withdrawal stream of gaseous nitrogen at a second withdrawal pressure level below the liquefaction pressure level and above the first withdrawal pressure level from the air separation unit.

[0027] Said compressing the gaseous nitrogen withdrawn from the air separation unit to a liquefaction pressure level may include, in certain embodiments, pressurizing nitrogen of the first withdrawal stream to the second withdrawal pressure level, combining the nitrogen of the first withdrawal stream at the second withdrawal pressure level with nitrogen of the second withdrawal stream to form a liquefaction feed stream, and compressing the liquefaction feed stream to the liquefaction pressure level. This represents a particularly advantageous way to reach the liquefaction pressure level.

[0028] Flash gas formed by said expanding of the liquid nitrogen to the one or more storage pressure levels into the one or more storage units may, in embodiments as disclosed herein, be heated in the heat transfer system. In such embodiments, the nitrogen of the first withdrawal stream may be combined with the flash gas heated in the heat transfer system to form a combined nitrogen stream before said pressurization to the second withdrawal pressure level. This allows for a particularly advantageous reutilization of the flash gas in corresponding embodiments.

[0029] The air products may generally include liquid nitrogen collected in the one or more storage units and at least one of liquid oxygen and liquid argon withdrawn in liquid form from a rectification column system of the air separation unit. Further air products may include, as mentioned, liquid air, and noble gas concentrates or mixtures. An air separation unit as proposed herein may therefore particularly comprise any rectification columns that are required for corresponding air products, such as, but not limited to, an argon column or argon column system (a dummy argon column as defined in, e.g., EP 3 343 158 A1 or complete argon system as known from textbooks as cited at the outset, either with a separated or integrated column), and may be equipped with apparatus for formation of the noble gas mixtures.

[0030] In embodiments, a flow rate at which the gaseous nitrogen is withdrawn from the air separation unit may be flexible and may generally set or selected to be higher than 40% of a total flow rate of air supplied to, and separated in, the air separation unit. The first part of liquid

nitrogen introduced in the air separation unit may generally set or selected to be adequate to fulfil the cold demand for the production of liquid oxygen or argon and may generally be higher than 20% of said total flow rate of air.

[0031] The liquefaction pressure may generally be supercritical and, in embodiments, higher than 50 bar and/or the evaporation pressure level may be higher than 30 or 70 bar. This allows for a particularly high efficiency and/or to fulfil specific demands.

[0032] The proposed apparatus for providing air products comprises an air separation unit and a nitrogen liquefaction unit including a heat transfer system. Said apparatus is configured to cryogenically separate air in the air separation unit, to withdraw gaseous nitrogen from the air separation unit, to compress the gaseous nitrogen withdrawn from the air separation unit to a liquefaction pressure level, to pass the gaseous nitrogen at the liquefaction pressure level through a heat transfer system to form pressurized liquid nitrogen at the liquefaction pressure level, to expand a first part of the pressurized liquid nitrogen from the liquefaction pressure level to a rectification pressure level, to introduce the first part of the liquid nitrogen expanded to the rectification pressure level into the air separation unit, to expand one or more further parts of the liquid nitrogen from the liquefaction pressure level to one or more storage pressure levels, and to introduce the one or more further parts of the liquid nitrogen expanded to the one or more storage pressure levels into one or more storage units.

[0033] As proposed, the apparatus is further configured to convert liquid hydrogen to form pressurized gaseous hydrogen including pressurizing the liquid hydrogen to an evaporation pressure level, and evaporating the liquid hydrogen in the heat transfer system at the evaporation pressure level.

[0034] For further details in relation to the apparatus as provided according to the present disclosure and preferred embodiments thereof, reference is made to the explanations relating to the proposed method and its preferred embodiments above.

[0035] Advantageously, the proposed apparatus is adapted to perform a method in at least one of the embodiments explained before in more detail.

Brief Description of the Drawings

[0036]

Figure 1 illustrates background aspects of an apparatus according to an embodiment,

Figure 2 illustrates background aspects of a method according to an embodiment,

Figure 3 illustrates background aspects of an apparatus according to an embodiment,

Figure 4 illustrates background aspects of a method according to an embodiment,

Figure 5 illustrates an apparatus according to an embodiment, and

Figure 6 illustrates an apparatus according to an embodiment.

10 Embodiments

[0037] In the Figures, elements of identical, essentially identical, functionally comparable, or technically comparable function and/or purpose may be identified with identical reference numerals, and repeated explanations may be omitted for reasons of conciseness. Explanations relating to devices, apparatus, arrangements, systems, etc., according to certain embodiments likewise may apply to methods, processes, procedures, etc., according to certain embodiments, and vice versa.

[0038] 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.

[0039] For conversion of liquid hydrogen to pressurized gaseous hydrogen, the liquid hydrogen may be pressurized from a first pressure to a second pressure, e.g., by means of a cryogenic pump, and thereafter warmed up to a temperature close to ambient temperature by applying heat power from an external source by means of a heat exchanger, often referred to as evaporator.

[0040] Reference is made expert literature and to Figure 1 described hereinbelow, which illustrates an apparatus 10 for converting liquid hydrogen to pressurized gaseous hydrogen. The purpose of using apparatus 10, or similar type of apparatus, is that the hydrogen after pressurization is still very cold, i.e., the temperature is usually lower than 40 K, and this stream therefore has considerable value in terms of (cooling) power. Coupling of hydrogen evaporation with an application requiring cold, such as nitrogen liquefaction in the example of

Figure 1, is therefore advantageous.

[0041] In Figure 1, a heat exchanger is indicated with reference numeral 11, a cryogenic pump is indicated with reference numeral 12, an optional heater is indicated with reference numeral 13, a storage tank for liquid nitrogen is indicated with reference numeral 14, and an expansion valve is indicated with reference numeral 15.

[0042] In Figure 1, moreover, liquid hydrogen is referred to with LH2, pressurized gaseous nitrogen with PGH2, and the first and second pressures mentioned are referred to with p1 and p2. A temperature of the liquid hydrogen LH2 before being passed through heat exchanger 11 may be in a range of about 30 to 40 K.

[0043] Heat exchanger 11 is operated using high pressure gaseous nitrogen HPGAN which is provided in a dry state and an uncontaminated form at a supercritical pressure p11, for example using an air separation unit as discussed below.

[0044] Gaseous nitrogen HPGAN is passed through heat exchanger 11 and withdrawn therefrom at a temperature in a range of about 75 to 90 K before being expanded in expansion valve 15 to a pressure p12 and into storage tank 14. For clarity, a stream formed from the liquid hydrogen LH2 is referred to with 1 and a stream formed from the pressurized gaseous nitrogen HPGAN is referred to with 2.

[0045] From storage tank 14, liquid nitrogen LIN and optionally gaseous nitrogen GAN, i.e., flash gas, may be withdrawn. Alternatively or additionally to the latter, gaseous nitrogen GAN may optionally be heated in heat exchanger 11 and may be withdrawn from apparatus 10 at the warm end. After leaving the heat exchanger, this gas can be vented into ambient. Optionally, it may be re-compressed to a high-pressure level and added to the main nitrogen flow. These options are indicated by dashed lines. Again, reference is made to the explanations below.

[0046] Therefore, as mentioned in other words before, in apparatus 10, cold pressurized hydrogen LH2 (after pressurization) is passed through heat exchanger 11 from the cold end to the warm end, and warm (ambient temperature) pressurized gaseous nitrogen HPGAN is provided through the other channels of the heat exchanger 11 in counterflow to the cold pressurized hydrogen LH2 stream 1, i.e., from the warm end to the cold end of heat exchanger 11. In heat exchanger 11, the cold pressurized hydrogen LH2 stream 1 is warmed up, and simultaneously the pressurized gaseous nitrogen HPGAN stream 2 is cooled to a temperature level of 80 K and liquefied, due to heat exchange through the heat exchanger surface, wherein the cooling capacity of the cold pressurized hydrogen LH2 stream 1 is applied to the warm pressurized nitrogen stream 2, HPGAN. Apparatus 10 may be used if large amounts of nitrogen need to be liquefied, and if a high efficiency of the process is targeted for.

[0047] Some or all pressures used in apparatus 10 may be the result of design considerations, e.g., low pressure

level p12 may be defined by a storage design pressure. For example, if a flat bottom tank is used for storage, the pressure level p12 may be selected to be very close to the ambient pressure. If a cylindrical storage vessel is used, the pressure level p12 may usually still be lower than 10 bar.

[0048] Liquid hydrogen LH2 which is pressurized from a first pressure p1 to a second, high pressure p2 by means of cryogenic pump 12 is passed through heat exchanger 11 in counter-current flow to the main nitrogen stream HPGAN. The hydrogen LH2 is heated there. Ideally, the hydrogen leaves the heat exchanger 11 with a temperature close to ambient temperature. Sometimes, the process properties (temperature profile) are nonoptimal and the hydrogen leaves the heat exchanger with a lower temperature. In this case, it can be warmed up further, by means of a separate heater (heat exchanger) by heat provided from an external heat source in heater 13.

[0049] In Figure 2, typical temperature profiles in a heat exchanger used for converting liquid hydrogen to pressurized gaseous hydrogen and simultaneously liquefying pressurized gaseous nitrogen, such as heat exchanger 11 as illustrated in Figure 1, are indicated in a diagram in which an amount of heat, Q, in kW, is indicated on the horizontal axis and a temperature, T, in K, is indicated on the vertical axis. The upper graph corresponds to the temperature profile for (liquefying) nitrogen at, in the specific example, 65 bar, which is cooled, in the example, to 82 K, and the lower graph corresponds to the temperature profile for (evaporating) hydrogen at, in the example, 60 bar.

[0050] The pressurized hydrogen LH2 (after pressurization) is, as mentioned, and as can directly be seen from Figure 2, still very cold. The temperature of this stream is usually lower than 40 K, which is also lower than the solidification temperature of nitrogen at about 63 K. The risk that the nitrogen stream can be solidified inside of the heat exchanger (if cooled to a temperature below 63 K) is therefore high. In case of nitrogen solidification, the nitrogen channels of the heat exchanger will be blocked, and an operation may be no longer possible. Usually, the system needs to be stopped for maintenance (warming-up, removal of solids etc.).

[0051] In embodiments disclosed herein, therefore, a corresponding method and apparatus is changed in such a way that the coldest hydrogen stream (after pressurization) is never thermally (indirectly) contacted with to the coldest nitrogen stream. Therefore, the risk of solidification of nitrogen and blockage of heat exchanger is minimized.

[0052] A corresponding apparatus is shown in Figure 3. Elements already explained in connection with Figure 1 are indicated with like reference numerals. An essential difference is that, instead of a single heat exchanger, such as heat exchanger 11 in Figure 1, a first heat exchanger and a second heat exchanger, which are, for reasons of generality, referred to as "first heat transfer

unit" and "second heat transfer unit" and indicated with 211 and 212, are used. A heat transfer system including first and second heat transfer units is indicated with reference numeral 210. As mentioned, first and second heat transfer units 211 and 212 may be provided as connected or unconnected heat exchanger blocks or may be integrated into a single heat transfer apparatus as generally known in the field.

[0053] As shown in Figure 3, for converting liquid hydrogen LH2 to pressurized gaseous hydrogen PGH2, wherein the liquid hydrogen LH2 is pressurized from a first pressure p1 to a second pressure p2 using cryogenic pump 12, the pressurized liquid hydrogen LH2 is passed through the heat transfer system 210. Gaseous nitrogen HPGAN is also passed through the heat transfer system 210.

[0054] The liquid hydrogen LH2 is passed cocurrently with the gaseous nitrogen HPGAN through the second heat transfer unit 212 and countercurrently with the gaseous nitrogen HPGAN through the first heat transfer unit 211. In this connection, the liquid hydrogen LH2 is passed through the second heat transfer unit 212 and thereafter through the first heat transfer unit 211, and the gaseous nitrogen HPGAN is passed through the first heat transfer unit 211 and thereafter through the second heat transfer unit 212, as mentioned above.

[0055] In Figure 4, typical temperature profiles in a heat transfer system 210, e.g. as illustrated in Figure 3, are shown. The left part referred to with 212a corresponds to second heat transfer unit 212 while the right part referred to with 211a corresponds to first heat transfer unit 211 as illustrated in Figure 3. As in Figure 2, an amount of heat, Q, in kW, is indicated on the horizontal axis and a temperature, T, in K, is indicated on the vertical axis. The upper graph corresponds to the temperature profile for (liquefying) nitrogen at, in the specific example, and as above, 65 bar, which is cooled, in the example, and as above to 82 K, and the lower (interrupted) graph corresponds to the temperature profile for hydrogen at, in the example, and as above, 60 bar.

[0056] As can be seen, the coldest hydrogen thermally contacts nitrogen at a pressure considerably higher than before, eliminating the risk of solidification.

[0057] In Figure 5, an apparatus 1000 according to an embodiment is illustrated. Said apparatus 1000 comprises an air separation unit 100 and a nitrogen liquefaction unit 200. Nitrogen liquefaction unit 200 may, particularly in the parts indicated with identical reference numerals, correspond to the apparatus shown in Figure 3.

[0058] Nitrogen liquefaction unit 200 comprises a heat transfer system 210 similar or identical to heat transfer system 210 as shown in Figure 3, but the liquid hydrogen LH2 is passed, in the example shown, countercurrently to the liquid nitrogen (as explained below) through the second heat transfer unit 212 of the heat transfer system 210. Liquefaction unit 200 further comprises a nitrogen compression system 16 with two compressors 16a, 16b

(or groups of compressor stages) and corresponding aftercoolers which are not individually indicated. Additionally to the storage tank for liquid nitrogen 14, which is provided as a pressure tank, a further tank 14a, which is provided as a flat-bottom tank, is part of nitrogen liquefaction unit 200. A corresponding expansion valve is labelled 15a. Either tank 14, 14a, or both, can be provided according to embodiments as disclosed herein.

[0059] Air separation unit 100 is configured to provide gaseous nitrogen gaseous nitrogen GAN, PGAN, at different pressure levels. Air separation unit 100 comprises a rectification column system 110 including a pressure column 111, a low-pressure column 112, and an argon column 113 (or an argon column system). Further parts of air separation unit 100 include a main air compressor 101 with an aftercooler, a prepurification unit 102 with a pre-cooler, a (simple and low-pressure) main heat exchanger 103, and a subcooler 104.

[0060] Air separation unit 100 may be operated as generally known in the art and from textbooks such as referred to at the outset. Briefly, atmospheric air AIR may be aspirated by main air compressor 101, prepurified in prepurification unit 102, cooled in main heat exchanger 103 and introduced, as gaseous pressurized air GAP, in pressure column 111 which may be operated at a pressure level of, e.g., 5 to 6 bar absolute pressure, such as about 5.3 bar absolute pressure at its top.

[0061] Enriched liquid collected in the bottom of pressure column 111 may be passed through subcooler 104 and thereafter used as coolant in a top condenser of argon column 113. Evaporated gas and unevaporated liquid from the top condenser may be fed into low-pressure column 112. Gas withdrawn from the top of pressure column 111 may be withdrawn and partially liquefied in a main condenser interconnecting pressure column 111 and low-pressure column 112. A liquid thus formed may be, on the one hand, reintroduced as a reflux into pressure column 111 and, on the other hand, passed through subcooler 104 and reintroduced as a reflux into low-pressure column 112.

[0062] Further gas withdrawn from the top of pressure column 111 at the operating pressure of pressure column 111 is heated in main heat exchanger 103 and passed as pressurized nitrogen PGAN into nitrogen liquefaction unit 200 as further explained below. Furthermore, pressurized liquid nitrogen HP-LIN is expanded from a liquefaction pressure level and introduced, as illustrated with dotted lines, into pressure column 111 and/or into low pressure column 112. Gaseous nitrogen GAN is withdrawn from low-pressure column 112 at the operating pressure thereof, heated in main heat exchanger 103 and passed as essentially unpressurized nitrogen PGAN into nitrogen liquefaction unit 200 as further explained below. Further withdrawn from low-pressure column 112 is, below one or more top separation sections thereof, a stream of impure nitrogen CGN which is also passed through subcooler 104, heated in main heat exchanger 103 and used in prepurification unit 102.

[0063] From the bottom of low-pressure column 112, liquid oxygen LOX is withdrawn, passed through sub-cooler 104, and provided as a liquid air product. A further liquid air product is withdrawn, as generally known in the art, in the form of liquid argon LAR from argon column 113 from which also a waste gas is withdrawn. Argon column 113 is interconnected with low-pressure column 112 as also known per se.

[0064] Operation of nitrogen liquefaction unit 200 includes withdrawing gaseous nitrogen GAN, PGAN, from the air separation unit 100, compressing the gaseous nitrogen GAN, PGAN withdrawn from the air separation unit 100 to a liquefaction pressure level, and passing the gaseous nitrogen GAN, PGAN at the liquefaction pressure level through the heat transfer system 210.

[0065] More particularly, withdrawing the gaseous nitrogen GAN, PGAN from the air separation unit 100 includes withdrawing a first withdrawal stream of gaseous nitrogen, which is the stream of essentially uncompressed gaseous nitrogen GAN withdrawn from the low-pressure column as explained above, at a first withdrawal pressure level below the liquefaction pressure level from the air separation unit 100 and further includes withdrawing a second withdrawal stream of gaseous nitrogen, which is the stream of pressurized gaseous nitrogen PGAN withdrawn from the pressure column 111 as explained above, at a second withdrawal pressure level below the liquefaction pressure level and above the first withdrawal pressure level from the air separation unit 100. The first withdrawal pressure level is typically the operating pressure level of the low-pressure column 112 and the second withdrawal pressure level is typically the operating pressure level of the pressure column 111, as also explained above.

[0066] The compression is performed using the compressor system 16 in the example shown. More precisely, nitrogen of the first withdrawal stream GAN (and a flash gas as explained below) is compressed using compressor 16b to the second withdrawal pressure level, combined with nitrogen of the first withdrawal stream PGAN at the second withdrawal pressure to form a liquefaction feed stream, and the liquefaction feed stream is further compressed using compressor 16a to the liquefaction pressure level. The liquefaction feed stream, which is labelled 2 as above, is then passed through first heat transfer unit 211 and then through second heat transfer unit 212.

[0067] As a result of the liquefaction, liquid nitrogen HP-LIN is formed at the liquefaction pressure level, and a first part thereof is expanded from the liquefaction pressure level to a rectification pressure level and introduced into the air separation unit 100, namely, as mentioned, either into pressure column 111 or low-pressure column 112. One or more further parts of the liquid nitrogen from the liquefaction pressure level HP-LIN is expanded and introduced in one of, or both, storage tanks 14, 14a via the corresponding valves 15, 15a.

[0068] In Figure 6, an apparatus 2000 according to a

further embodiment is illustrated. Said apparatus 2000 is configured essentially configured the same as apparatus 1000 shown in Figure 5, but the nitrogen liquefaction unit 200 essentially includes a configuration such as shown for the apparatus of Figure 3, i.e., including a cocurrent flow of liquid hydrogen LH2 and nitrogen PGAN through second heat transfer unit 212.

10 Claims

1. A method for providing air products (LIN, PLIN, LOX, LAR), said method including cryogenically separating air in an air separation unit (100), withdrawing gaseous nitrogen (GAN, PGAN) from the air separation unit (100), compressing the gaseous nitrogen (GAN, PGAN) withdrawn from the air separation unit (100) to a liquefaction pressure level, passing the gaseous nitrogen (GAN, PGAN) at the liquefaction pressure level through a heat transfer system (210) to form pressurized liquid nitrogen (HP-LIN) at the liquefaction pressure level, expanding a first part of the pressurized liquid nitrogen (HP-LIN) from the liquefaction pressure level to a rectification pressure level, introducing the first part of the liquid nitrogen expanded to the rectification pressure level into the air separation unit (100), expanding one or more further parts of the liquid nitrogen from the liquefaction pressure level (HP-LIN) to one or more storage pressure levels, and introducing the one or more further parts of the liquid nitrogen (PLIN, LIN) expanded to the one or more storage pressure levels into one or more storage units (14, 14a), wherein the method includes converting liquid hydrogen (LH2) to form pressurized gaseous hydrogen (HPGH2) including pressurizing the liquid hydrogen (LH2) to an evaporation pressure level, and evaporating the liquid hydrogen (LH2) in the heat transfer system (210) at the evaporation pressure level.
2. The method according to claim 1, wherein the heat transfer system comprises a first heat transfer unit (211) and a second heat transfer unit (212), wherein said passing the gaseous nitrogen (GAN, PGAN) at the liquefaction pressure level through the heat transfer system (210) to form pressurized liquid nitrogen (HP-LIN) at the liquefaction pressure level includes first passing the gaseous nitrogen (GAN, PGAN) at the liquefaction pressure level through the first heat transfer unit (211) and thereafter through the second heat transfer unit (212).
3. The method according to claim 2, wherein said evaporating the liquid hydrogen (LH2) in the heat transfer system (210) at the evaporation pressure level includes passing the liquid hydrogen (LH2) cocurrently or countercurrently to the gaseous nitrogen (GAN, PGAN) at the liquefaction pressure level

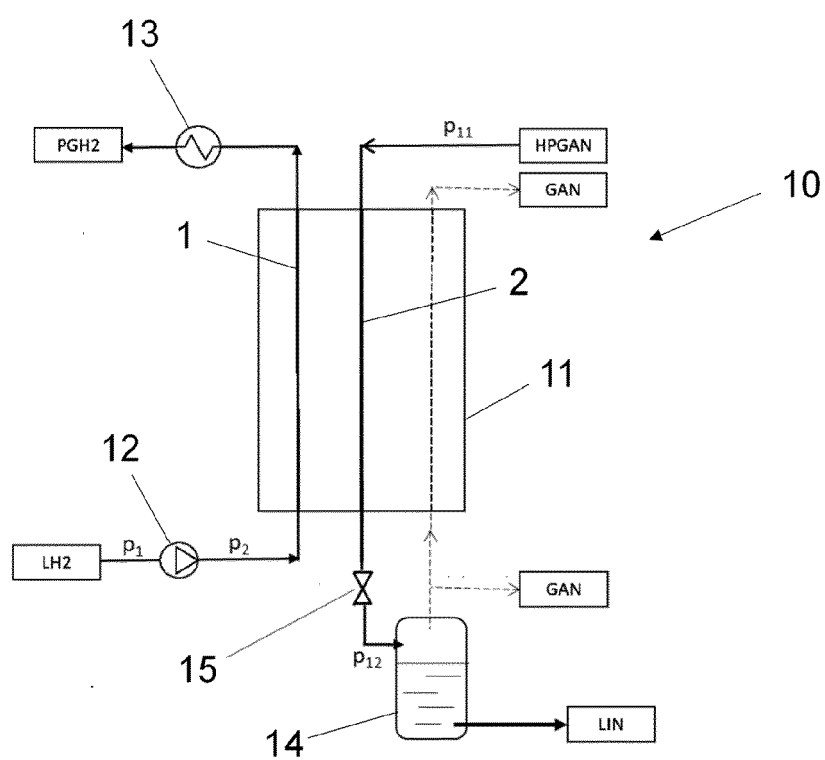
through the second heat transfer unit (212) and thereafter passing the liquid hydrogen (LH2) countercurrently to the gaseous nitrogen (GAN, PGAN) at the liquefaction pressure level through the first heat transfer unit (211).

4. The method according to any one of the preceding claims, wherein said withdrawing the gaseous nitrogen (GAN, PGAN) from the air separation unit (100) includes withdrawing a first withdrawal stream of gaseous nitrogen (GAN) at a first withdrawal pressure level below the liquefaction pressure level from the air separation unit (100) and further includes withdrawing a second withdrawal stream of gaseous nitrogen (PGAN) at a second withdrawal pressure level below the liquefaction pressure level and above the first withdrawal pressure level from the air separation unit (100). 10
5. The method according to claim 4, wherein said compressing the gaseous nitrogen (GAN, PGAN) withdrawn from the air separation unit (100) to a liquefaction pressure level includes pressurizing nitrogen of the first withdrawal stream to the second withdrawal pressure level, combining the nitrogen of the first withdrawal stream at the second withdrawal pressure level with nitrogen of the second withdrawal stream to form a liquefaction feed stream, and compressing the liquefaction feed stream to the liquefaction pressure level. 15 20 25 30
6. The method according to any of the preceding claims, wherein flash gas formed by said expanding of the liquid nitrogen (PLIN, LIN) to the one or more storage pressure levels into the one or more storage units (14, 14a) is heated in the heat transfer system (200). 35
7. The method according to claim 6 when depending from claim 6, wherein the nitrogen of the first withdrawal stream is combined with the flash gas heated in the heat transfer system (200) to form a combined nitrogen stream before said pressurization to the second withdrawal pressure level. 40 45
8. The method according to any one of the preceding claims, wherein the air products (LIN, PLIN, LOX, LAR) include liquid nitrogen (LIN, PLIN) collected in the one or more storage units (231, 232) and at least one of liquid oxygen (LOX) and liquid argon (LAR) withdrawn in liquid form from a rectification column system (110) of the air separation unit (100). 50
9. The method according to any one of the preceding claims, wherein a flow rate at which the gaseous nitrogen (GAN, PGAN) is withdrawn from the air separation unit (100) is higher than 40% of a total flow rate of air supplied to, and separated in, the air 55

separation unit (100).

10. The method according to any one of the preceding claims, wherein the liquefaction pressure level is higher than 50 bar and/or wherein the evaporation pressure level is higher than 30 or 70 bar. 5
11. An apparatus (1000, 2000) for providing air products (LIN, PLIN, LOX, LAR), said apparatus (1000, 2000) comprising an air separation unit (100) and a nitrogen liquefaction unit (200) comprising a heat transfer system (210), wherein said apparatus (1000, 2000) is configured to cryogenically separate air in the air separation unit (100), to withdraw gaseous nitrogen (GAN, PGAN) from the air separation unit (100), to compress the gaseous nitrogen (GAN, PGAN) withdrawn from the air separation unit (100) to a liquefaction pressure level, to pass the gaseous nitrogen (GAN, PGAN) at the liquefaction pressure level through a heat transfer system (210) to form pressurized liquid nitrogen (HP-LIN) at the liquefaction pressure level, to expand a first part of the pressurized liquid nitrogen (HP-LIN) from the liquefaction pressure level to a rectification pressure level, to introduce the first part of the liquid nitrogen expanded to the rectification pressure level into the air separation unit (100), to expand one or more further parts of the liquid nitrogen from the liquefaction pressure level (HP-LIN) to one or more storage pressure levels, and to introduce the one or more further parts of the liquid nitrogen (PLIN, LIN) expanded to the one or more storage pressure levels into one or more storage units (14, 14a), wherein apparatus (1000, 2000) is further configured to convert liquid hydrogen (LH2) to form pressurized gaseous hydrogen (HPGH2) including pressurizing the liquid hydrogen (LH2) to an evaporation pressure level, and evaporating the liquid hydrogen (LH2) in the heat transfer system (210) at the evaporation pressure level. 10 15 20 25 30 35 40 45
12. The apparatus (100) according to claim 12, configured to perform a method according to any one of claims 1 to 10. 50 55

Fig. 1



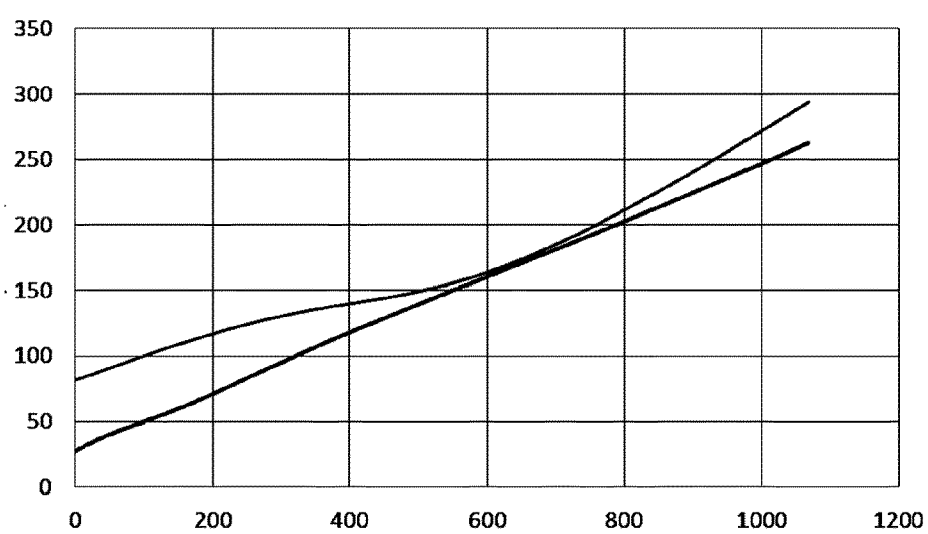
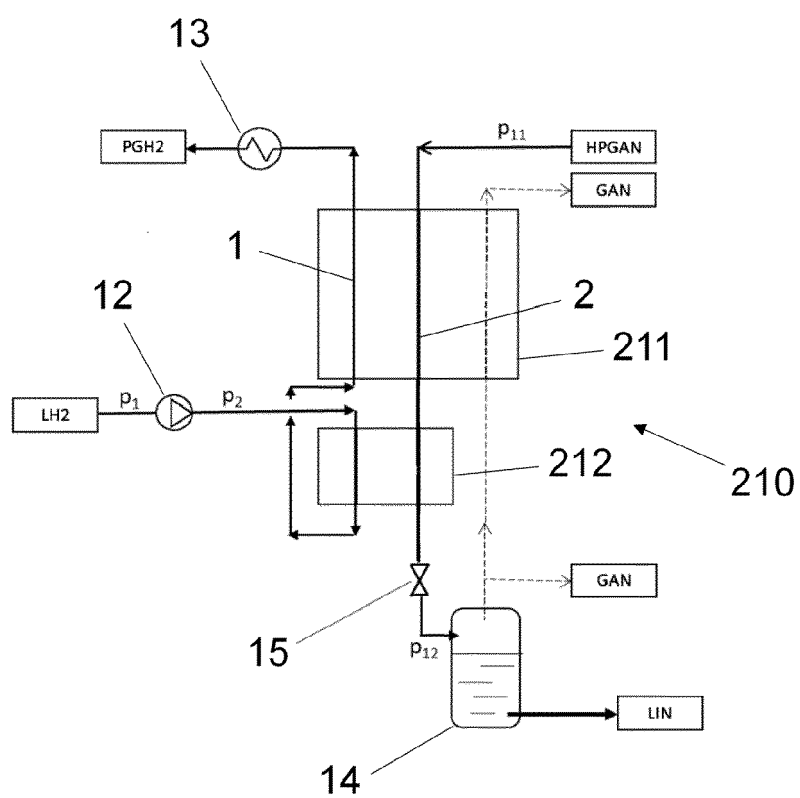


Fig. 2

Fig. 3



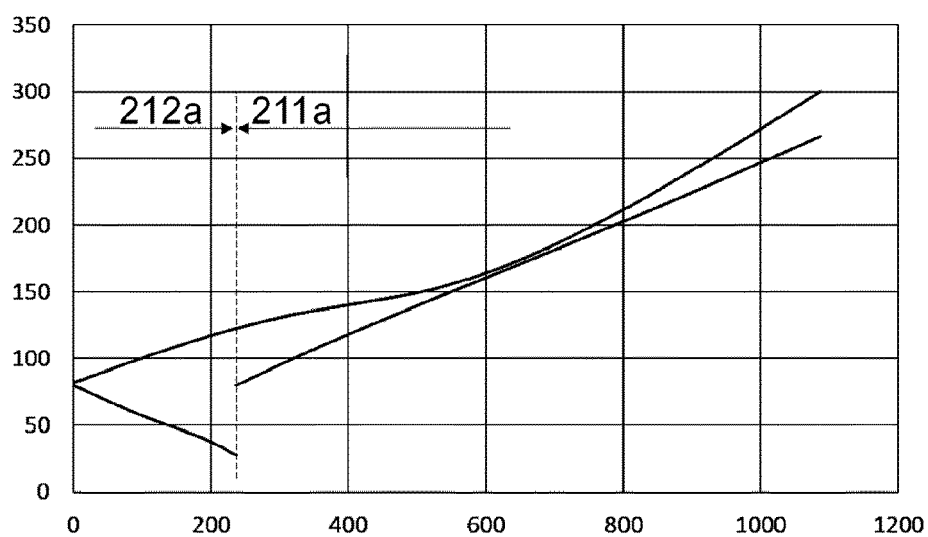


Fig. 4

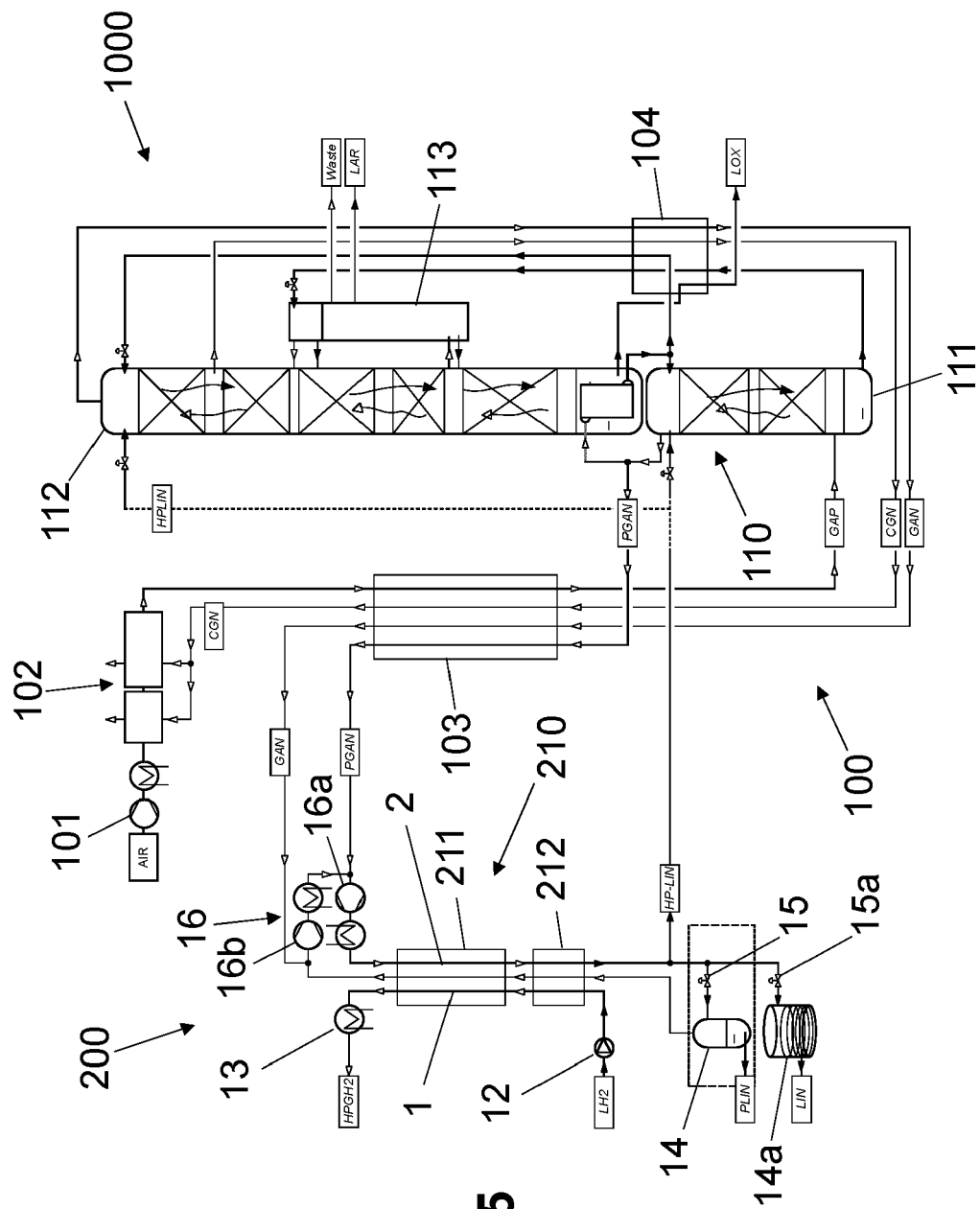


Fig. 5

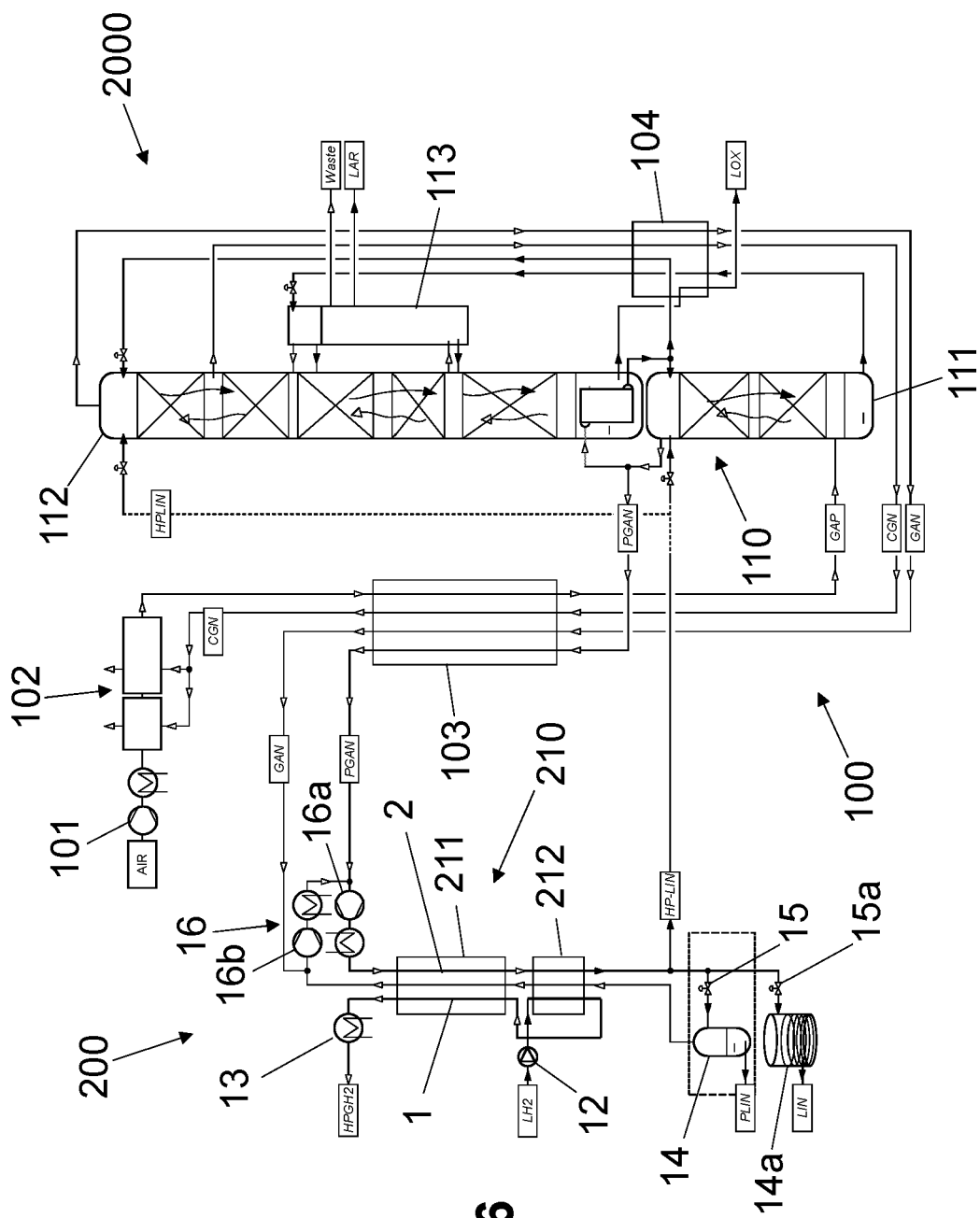


Fig. 6



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Application Number

EP 23 02 0408

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