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(54) **METHOD AND DEVICE FOR GENERATING ELECTRICAL ENERGY**

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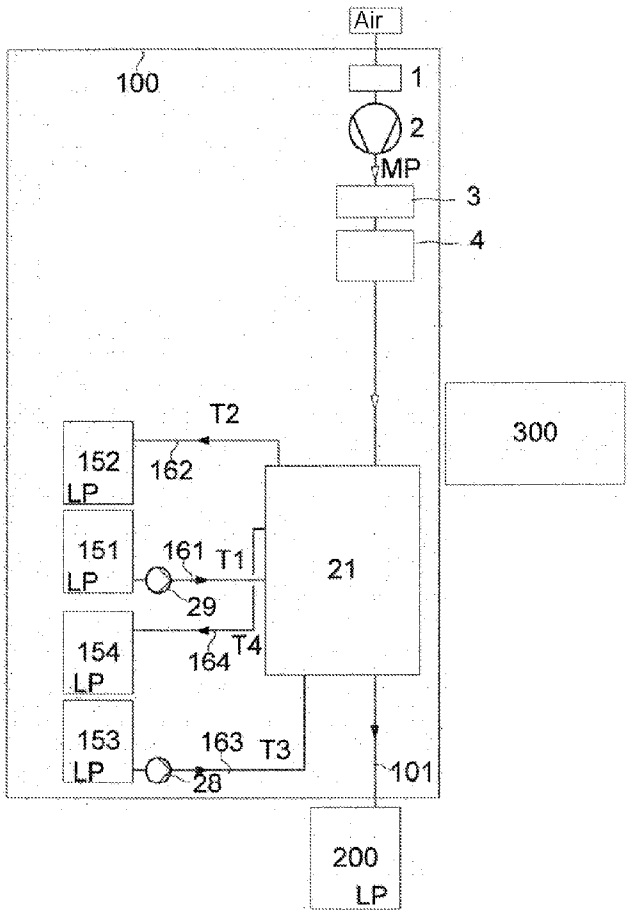
(57) **ABSTRACT**

The invention relates to a combined system for generating electrical energy consisting of a power plant and an air handling system. The power plant comprises a first gas expansion unit connected to a generator. The air handling system comprises an air compression unit, a heat exchange system, and a fluid tank. In a first operating mode, feed air is compressed in the air compression unit and cooled in the heat exchange system against a first and a second coolant. A storage fluid is generated and stored as cryogenic fluid in the fluid tank. In a second operating mode, cryogenic fluid is removed from the fluid tank, vaporized, or pseudo-vaporized, at superatmospheric pressure, and heated in the heat exchange system against the second and first coolants.



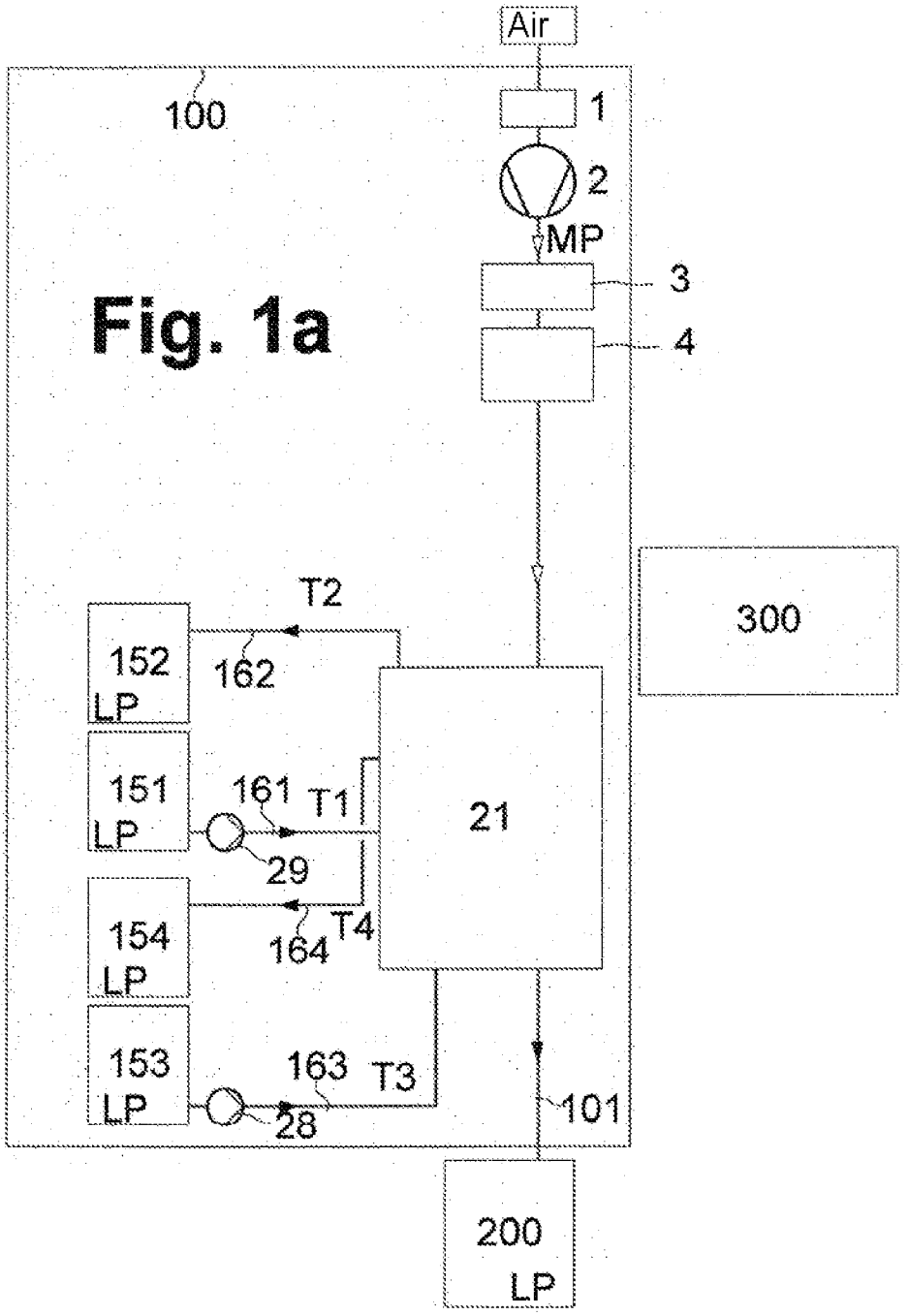

Air
100
1
2
MP
3
4
300
T2
152
LP
162
151
LP
161
T1
21
29
154
LP
164
T4
153
LP
163
T3
28
101
200
LP

Fig. 1a

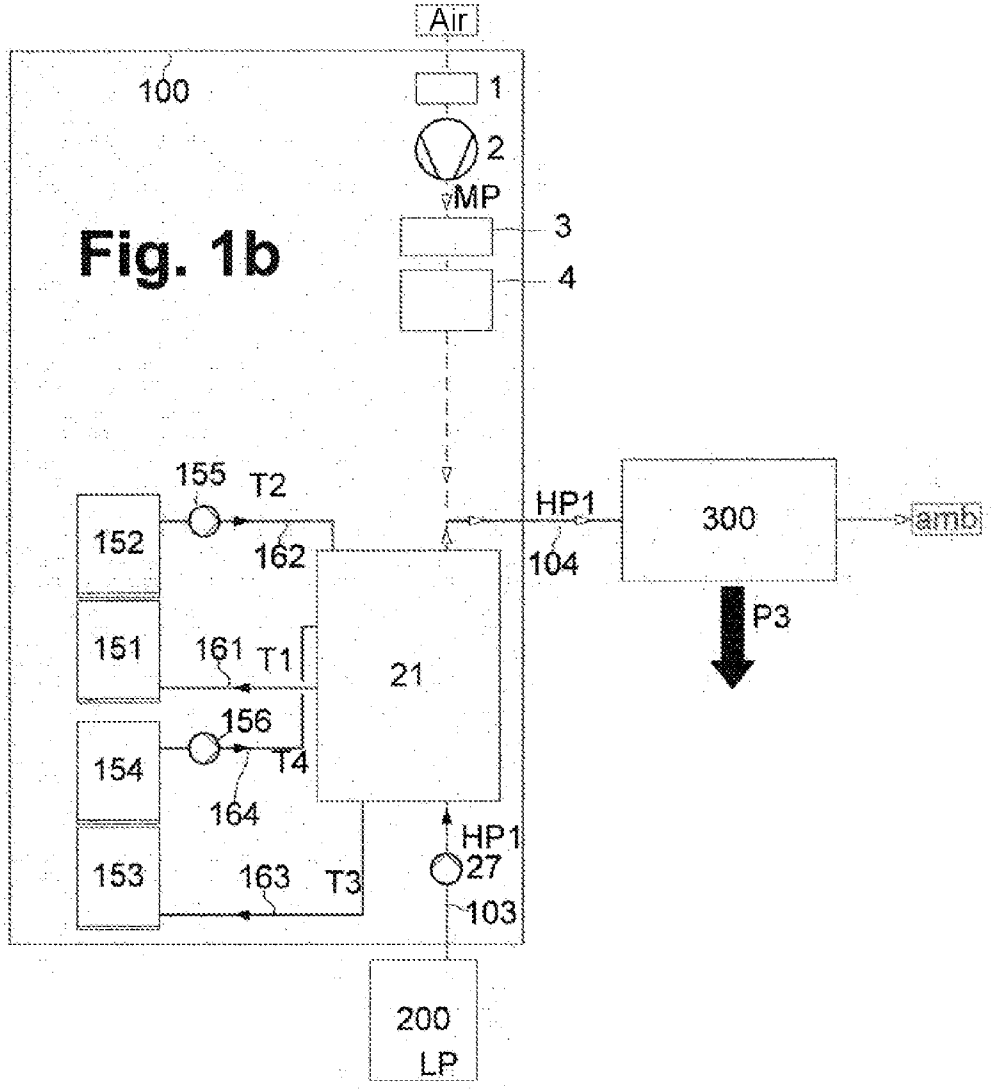
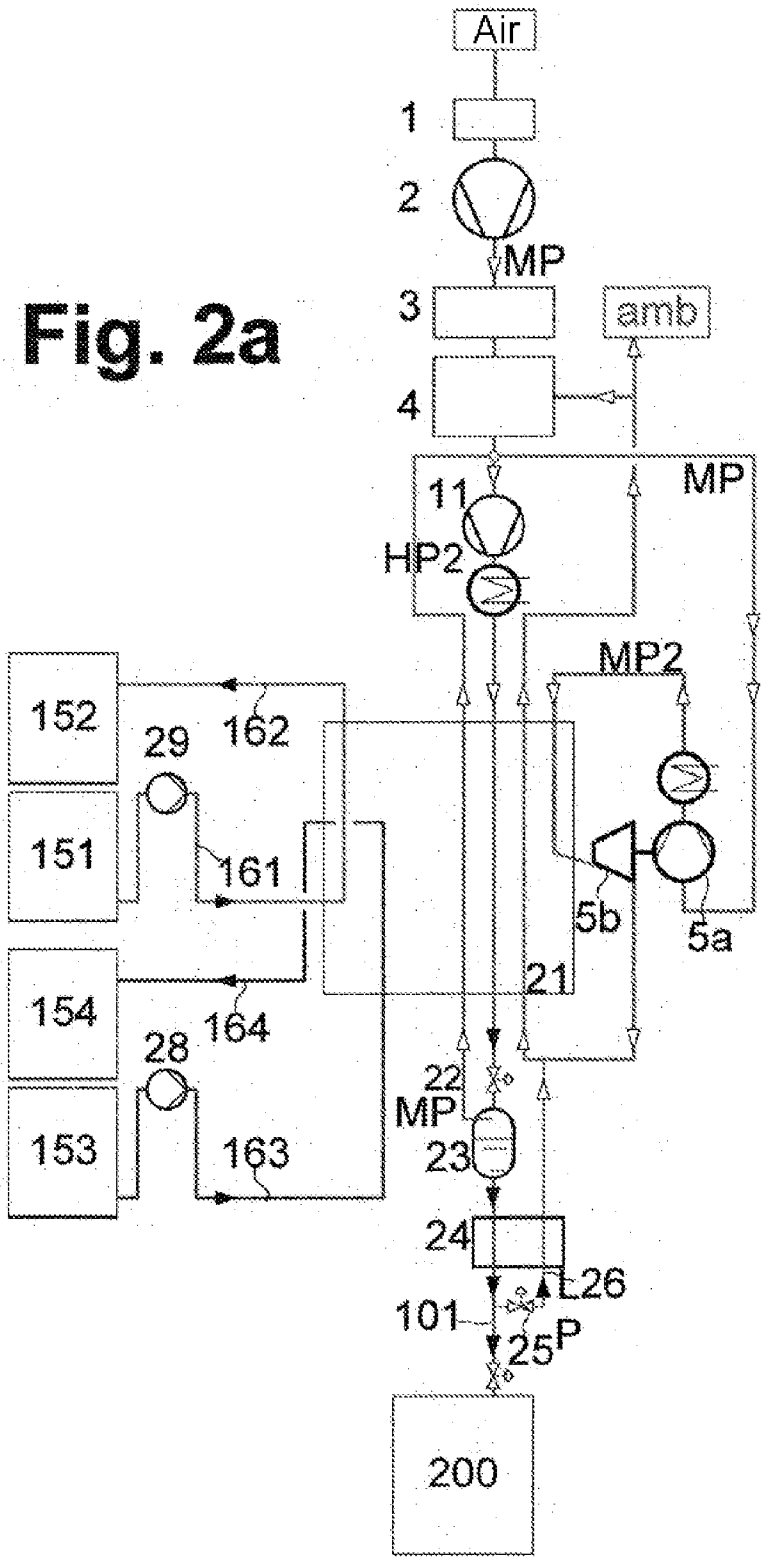

Air
100
1
2
MP
3
4
155
T2
152
162
HP1
300
amb
104
151
161
T1
21
P3
156
154
T4
164
HP1
153
163
T3
27
103
200
LP

Fig. 1b

Fig. 2a


Air
1
2
MP
3
amb
4
11
MP
HP2
MP2
152
29
162
151
161
5b
5a
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164
28
22
MP
153
163
23
24
26
101
25
P
200

Fig. 2b

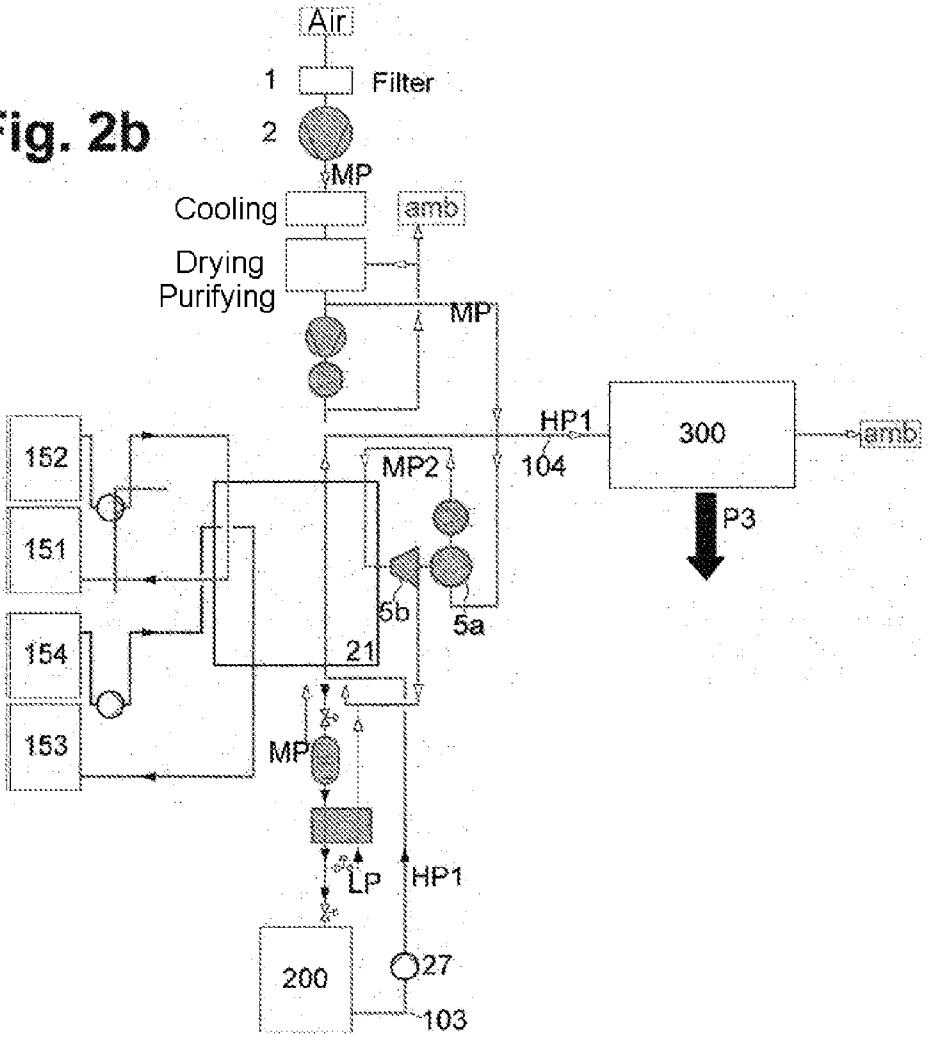

Air
1
Filter
2
MP
Cooling
amb
Drying
Purifying
MP
HP1
300
amb
152
MP2
104
151
P3
5b
5a
154
21
153
MP
LP
HP1
200
27
103

Fig. 3a

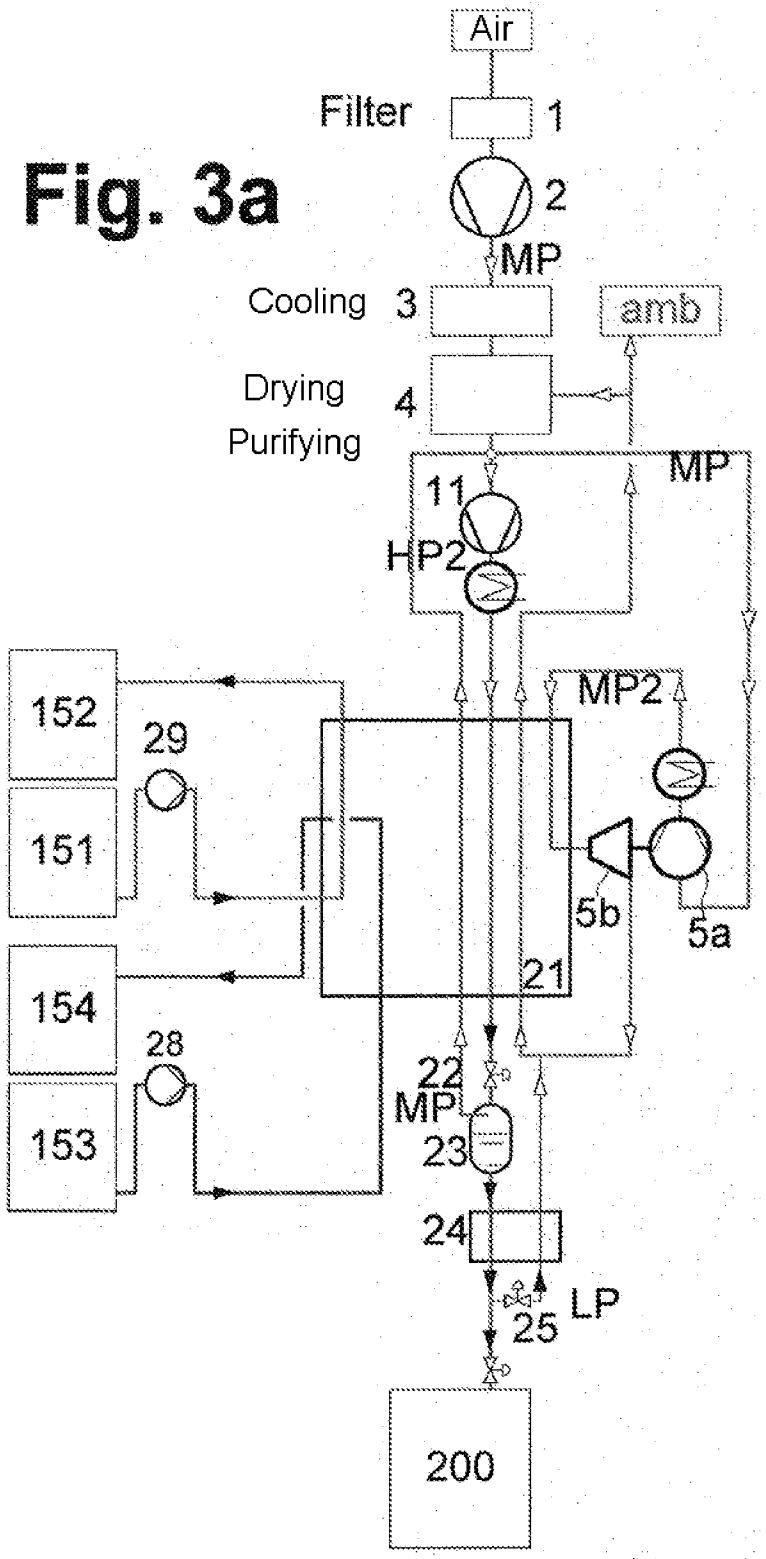
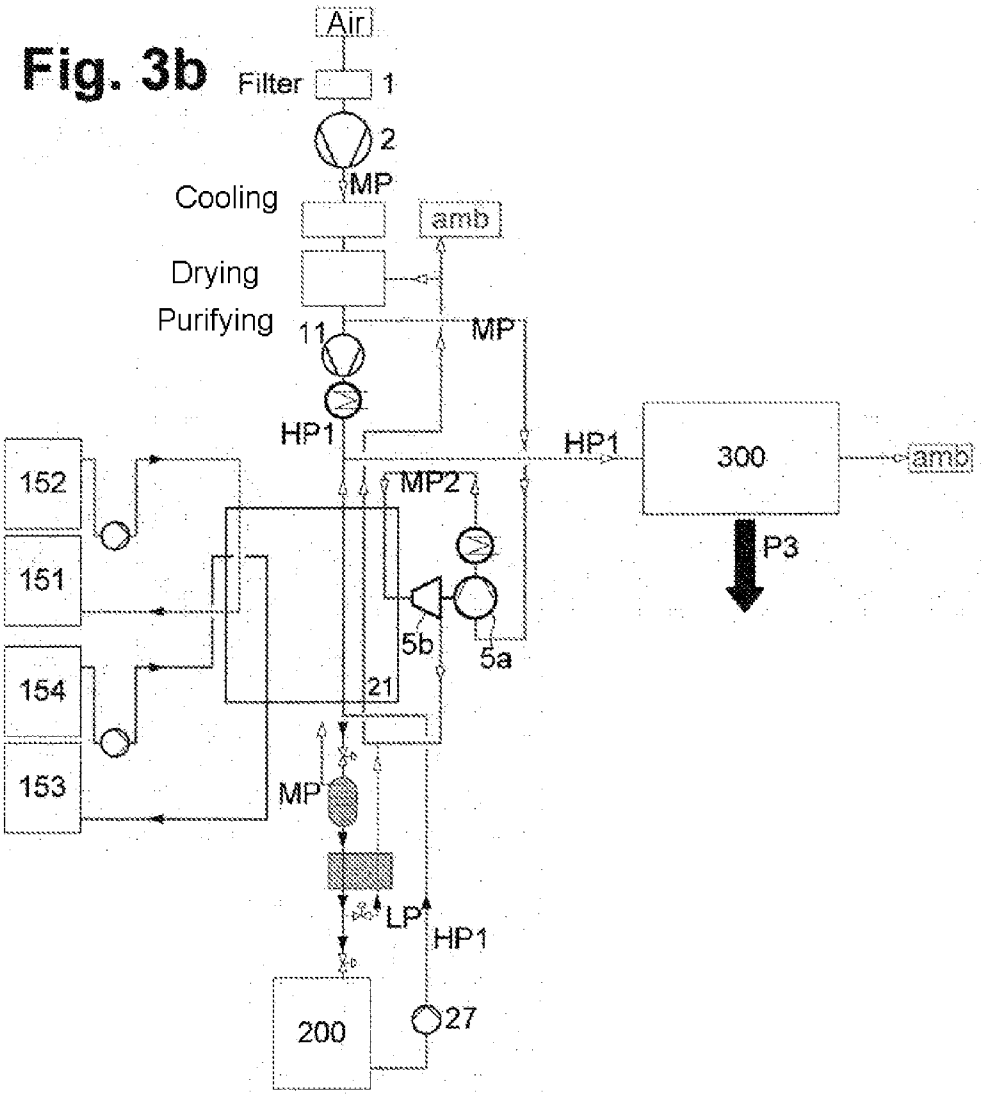
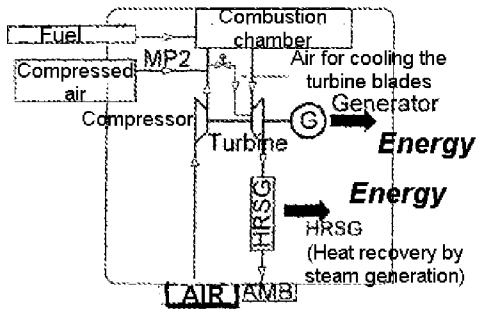

Air
Filter
1
2
MP
Cooling
3
amb
Drying
Purifying
4
MP
11
HP2
MP2
152
29
151
154
28
153
5b
5a
21
22
MP
23
24
25
LP
200

Fig. 3b


Air
Filter
1
2
MP
Cooling
amb
Drying
Purifying
11
MP
HP1
HP1
300
amb
152
MP2
151
P3
5b
5a
154
21
153
MP
LP
HP1
200
27


Fuel
Combustion chamber
MP2
Compressed air
Air for cooling the turbine blades
Generator
Compressor
Turbine
G
Energy
HRSG
Energy
HRSG
(Heat recovery by steam generation)
AIR
AMB
a)

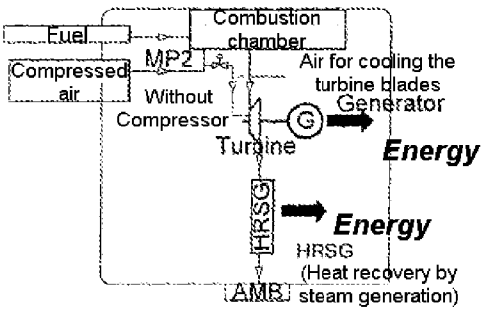
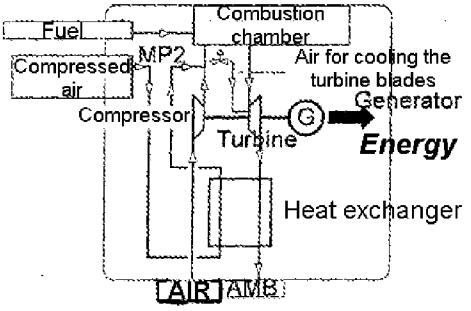

Fuel
Combustion chamber
MP2
Compressed air
Air for cooling the turbine blades
Without Compressor
Generator
Turbine
G
Energy
HRSG
Energy
HRSG
(Heat recovery by steam generation)
AMB
c)

Fig. 4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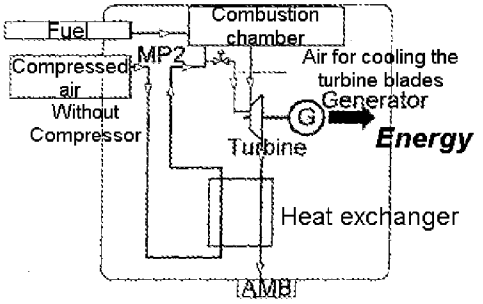
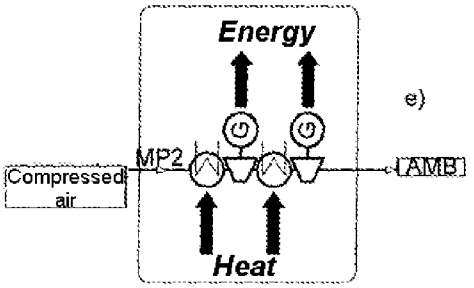
Combustion chamber
MP2
Compressed air
Air for cooling the turbine blades
Generator
Compressor
Turbine
G
Energy
Heat exchanger
AIR
AMB
b)


Fuel
Combustion chamber
MP2
Compressed air
Air for cooling the turbine blades
Without Compressor
Generator
Turbine
G
Energy
Heat exchanger
AMB
d)


Energy
G
G
e)
MP2
Compressed air
AMB
Heat

METHOD AND DEVICE FOR GENERATING ELECTRICAL ENERGY

[0001] The invention relates to a method and an apparatus for generating electrical energy as per the preamble of patent claim **1** and also to a corresponding apparatus.

[0002] A "cryogenic liquid" is understood to be a liquid the boiling point of which is below ambient temperature and is for example 220 K or lower, in particular lower than 200 K.

[0003] In its function as a "high-pressure stream", the cryogenic liquid may be at subcritical pressure during "vaporization". However, if the cryogenic liquid is brought to a superatmospheric pressure, which is above the critical pressure, there is no real phase change ("vaporization"), but rather what is termed "pseudo-vaporization".

[0004] The "heat exchanger system" serves to cool feed air for the air treatment plant in indirect heat exchange with one or more cold streams. It may be formed from a single heat exchanger portion or a plurality of heat exchanger portions connected in parallel and/or in series, for example from one or more plate heat exchanger blocks.

[0005] Methods and apparatuses which use liquid air or liquid nitrogen for grid regulation and for providing control power in power grids are known. At times of cheap power, here the ambient air is liquefied in an air separation plant with an integrated liquefier or in a separate liquefaction plant, and is stored in a liquid tank in the form of a cryogenic store. At times of peak load, the liquefied air is taken from the store, its pressure is raised in a pump and then it is warmed to about ambient temperature or higher. This hot high-pressure air is then expanded to ambient pressure in an expansion unit consisting of a turbine or a plurality of turbines with intermediate heating. The mechanical energy generated in the turbine unit is converted to electrical energy in a generator and is fed into the electrical grid as particularly valuable energy. Systems of this type are described in WO 2007096656 and in DE 3139567 A1.

[0006] A method of the type mentioned in the introduction and a corresponding apparatus are known from US 2001004830 A1.

[0007] Here, during the second operating mode, the cryogenic liquid at a very high pressure (200 bar) is brought into indirect heat exchange firstly with a first liquid refrigeration transfer medium in the heat exchanger system, and in the process is warmed up to about ambient temperature, is then expanded in an expansion turbine to the lower pressure (10 to 15 bar) and thereby cooled (to approximately −150° C.), and is then brought into indirect heat exchange with the second liquid refrigeration transfer medium, and warmed again in the process. As a whole, the cryogenic liquid is therefore brought into heat exchange with two liquid refrigeration transfer media at differing temperature, which emit sensible heat in the process. In this heat exchange in the heat exchanger system of the air treatment plant, both refrigeration transfer media remain liquid.

[0008] The refrigeration of the cryogenic liquid is therefore transferred to the two refrigeration transfer media at two different temperature levels, and is available again for generating the cryogenic liquid during the first operating mode. In contrast to the otherwise conventional (pseudo-)vaporization against a heat transfer medium such as atmospheric air or hot (water) vapor, the liquefaction refrigeration from the cryogenic storage liquid is not lost or is not entirely lost as a result. Two refrigeration transfer media are required in this method owing to the intermediate expansion in an expansion turbine, since in this operation the generation of the mechanical energy is accompanied by cryogenic cooling of the working fluid. The first phase (energy storage/liquefaction) of the method according to US 2001004830 A1 also consists of a plurality of steps: the incoming air (10 to 15 bar) is firstly brought into indirect heat exchange with the second liquid refrigeration transfer medium and cooled (to −150° C.), is then compressed (to 40 bar), is thereby warmed (−60° C. at the outlet), and is then brought into indirect heat exchange with the first liquid refrigeration transfer medium and cooled again (to −170° C.)

[0009] The invention is based on the object of improving a system of this type in terms of its economic viability and in particular of making a relatively simple design in terms of apparatus possible.

[0010] This object is achieved by the characterizing features of patent claim **1**. According to the invention, in the first operating mode, the feed air compressed in the air compression unit passes into indirect heat exchange with the first liquid refrigeration transfer medium and with the second liquid refrigeration transfer medium at the same pressure in the heat exchanger system. It is therefore the case that no machine needs to be used for increasing the pressure between the heat exchange with the first refrigeration transfer medium and the heat exchange with the second refrigeration transfer medium. This reduces the number of hardware components, such as heat exchangers, turbines and/or compressors; the costs for the liquid air storage plant as a whole are reduced and the economic viability of this application is increased.

[0011] Where pressures are stated in the patent claims, the natural pressure losses are not included. Pressures are referred to here as being "the same" when the pressure difference between the corresponding points is not greater than the natural losses in the line, which arise through pressure losses in pipelines, heat exchangers, coolers, adsorbers, etc.

[0012] In the invention, the two refrigeration transfer media are warmed in the first operating mode to the same temperature level T**2** or T**4**, from which they are cooled in the second operating mode. Conversely, they are cooled in the second operating mode to the same temperature T**1** or T**3**, from which they are warmed in the first operating mode. Owing to unavoidable losses, "the same temperature level" is to be understood as meaning not only exactly the same temperature, but also a temperature band with a range of up to 20 K. It is of course desirable to achieve the smallest possible temperature difference between the two operating modes.

[0013] As a result, the heat exchange diagram of the heat exchanger system can have a particularly favorable configuration. The temperature levels preferably lie in the following ranges:

[0014] T**1** (first refrigerant, lower level):

[0015] −145 to −45° C., for example −145° C.

[0016] T**2** (second refrigerant, upper level):

[0017] 10 to 30° C., for example 20° C.

[0018] T**3** (second refrigerant, lower level):

[0019] −190 to −160° C., for example −185° C.

[0020] T**4** (second refrigerant, upper level):

[0021] −100 to −45° C., for example −90° C.

[0022] The two refrigerants differ in their chemical composition, in particular in their boiling point. They have to be selected in such a way that they are liquid throughout the respective working range. Suitable for this purpose are, for example, ethanol (C_2H_5OH) as the first (hotter) refrigeration transfer medium and propane (C_3H_8) as the second (cooler)

refrigeration transfer medium. Moreover, the substances indicated in the table below are suitable in the invention for use as the first or second refrigeration transfer medium.

Systematic name	Common name	Melting point in ° C.	Boiling temperature in ° C.
methanol	wood spirit, methyl alcohol	−97.8	64.7
ethanol	alcohol, ethyl alcohol, spirit of wine	−114.1	78.3
propan-1-ol	n-propyl alcohol	−126.2	97.2
butan-1-ol	n-butyl alcohol	−89.3	117.3
pentan-1-ol	n-amyl alcohol	−78.2	138
hexan-1-ol	n-hexyl alcohol	−48.6	157.5
propan-2-ol	isopropyl alcohol, isopropanol	−88.5	82.3
butan-2-ol	secondary butyl alcohol	−114.7	99.5
2-methylpropan-1-ol	isobutyl alcohol	−108	108
pentan-2-ol	sec-n-amyl alcohol	−50	118.9
2-methylbutan-1-ol		−70	129
3-methylbutan-1-ol	isoamyl alcohol	−117	130.8
1,2-propanediol	propylene glycol	−68	188
butane-1,2-diol	1,2-butylene glycol	−114	192
butane-1,3-diol	1,3-butylene glycol	<−50	207.5
prop-2-en-1-ol	allyl alcohol	−129	97
pentan-1-ol	n-amyl alcohol	−78.2	128.0

[0023] It goes without saying that one or more further liquid refrigeration transfer media and also the mixtures thereof can also be used in the invention. As a result, the heat exchange diagram can be optimized further; however, the complexity in terms of apparatus and control is also increased.

[0024] In the invention, provision is preferably made of four liquid stores of liquid refrigeration transfer medium, that is to say one for each of the temperature levels. As a result, refrigeration transfer medium cooled in the second operating mode is available at the same temperature level for the first operating mode for cooling (and vice versa).

[0025] The warming and cooling of the refrigeration transfer media is carried out here in the heat exchanger system of the air treatment plant, which is present in any case for the cooling of the feed air in the first operating mode and the warming of the cryogenic liquid in the second operating mode.

[0026] Within the context of the invention, mechanical energy is generated from the high-pressure storage fluid in the second operating mode by either the storage fluid itself or a fluid derived therefrom being expanded in the gas expansion unit so as to perform work. The fluid derived therefrom may be formed for example by a mixture of the storage fluid with one or more other fluids, or by a reaction product of the storage fluid with one or more other substances. The latter may be formed for example by combustion exhaust gas if the storage fluid contains oxygen and is used for the combustion of a fuel.

[0027] The warming of the first refrigeration transfer medium in the first operating mode is preferably carried out in the same groups of passages of the heat exchanger system, in which the cooling of the first refrigeration transfer medium in the second operating mode is preferably carried out in the same groups of passages of the heat exchanger system, in which the cooling of the second refrigeration transfer medium in the second operating mode is carried out in the same groups of passages of the heat exchanger system. It is therefore possible for the same apparatus to be used in both operating modes.

[0028] Analogously thereto, the same pumps can be used in the first and in the second operating mode, in each case one for transporting the first and the second refrigeration transfer medium.

[0029] The temperature ranges of the two refrigeration transfer media can in principle be disjoint (T**4**<T**1**). It is preferable, however, that they overlap, in that the first temperature level T**1** is more than 18 K, in particular 20 to 70 K, below the fourth temperature level T**4**. This makes it possible to particularly effectively optimize the heat exchange diagram.

[0030] In principle, the air compression unit can be switched off in the second operating mode; in this case, heat for the (pseudo-)vaporization of the cryogenic liquid is supplied exclusively by the natural gas to be liquefied. In many cases, it may be beneficial, however, if feed air is compressed in the air compression unit and cooled in the heat exchanger system in the second operating mode, too. Although it appears at first glance to be disadvantageous to continue to operate the air compression unit in the second operating mode, in which the energy price is high, it has been found within the context of the invention that surprisingly major operational advantages are associated therewith, because the air compression unit does not have to be switched off and on when switching over between the operating modes, but instead continues to operate continuously. Moreover, the quantity of compressed feed air can be obtained as high-pressure gas and electrical energy can additionally be obtained therefrom.

[0031] In a first variant of the method according to the invention, in the second operating mode at least part of the generation of electrical energy from the gaseous high-pressure storage fluid is performed in the gas turbine expander of a gas turbine system of a gas turbine power plant, the storage fluid being fed to the gas turbine system downstream of the vaporization. The gas turbine system is then part of the gas expansion unit within the meaning of patent claim **1**. This use of the gas turbine system itself for obtaining energy from the high-pressure storage fluid is described in more detail in patent claims **5** and **6** and in the prior German patent application 102011121011 and the patent applications corresponding thereto.

[0032] A "gas turbine system" has a gas turbine (gas turbine expander) and a combustion chamber. In the gas turbine, hot gases from the combustion chamber are expanded so as to perform work. The gas turbine system may also have a gas turbine compressor driven by the gas turbine. Some of the mechanical energy generated in the gas turbine is commonly used to drive the gas turbine compressor. More of the mechanical energy is regularly converted in a generator to generate electrical energy.

[0033] In this variant, at least part of the generation of mechanical energy from the gaseous high-pressure storage fluid is performed in the gas turbine system of the power plant, that is to say in an apparatus present in any case in the power plant for converting pressure energy into mechanical drive energy. Within the context of the invention, an additional separate system for the work-performing expansion of the high-pressure storage fluid may be of less complex design or may be dispensed with entirely. In the simplest case, it is

possible in the invention for the entire generation of mechanical energy from the gaseous high-pressure storage fluid to be performed in the gas turbine system. The high-pressure storage fluid is then fed to the gas turbine system, for example at the pressure at which it is (pseudo-)vaporized.

[0034] In a second variant, the gas expansion unit has a hot-gas turbine system having at least one heater and a hot-gas turbine. The generation of electrical energy from the gaseous high-pressure storage fluid is carried out here at least partially as work-performing expansion in a hot-gas turbine system which has at least one heater and a hot-gas turbine. Here, the generation of energy from the high-pressure storage fluid takes place outside the gas turbine system.

[0035] The "hot-gas turbine system" may be formed with a single stage with a heater and a single-stage turbine. Alternatively, it may have a plurality of turbine stages, preferably with intermediate heating. It is expedient in any case to provide a further heater downstream of the last stage of the hot-gas turbine system. The hot-gas turbine system is preferably coupled to one or more generators for generating electrical energy.

[0036] A "heater" is understood here to be a system for the indirect heat exchange between a heating fluid and the gaseous storage fluid. It is thus possible to transfer residual heat or waste heat to the storage fluid and to use this heat for generating energy in the hot-gas turbine system.

[0037] The two variants may also be combined by the gas expansion unit having one or more hot-gas turbines as well as one or more gas turbine systems. The gaseous high-pressure storage fluid is then expanded in two steps, the first step being carried out as a work-performing expansion in the hot-gas turbine system and the second step being carried out in the gas turbine system, the gaseous high-pressure storage fluid being fed to the hot-gas turbine system, where it is expanded to an intermediate pressure, and a gaseous intermediate-pressure storage fluid being removed from the hot-gas turbine system and finally being fed to the gas turbine system.

[0038] The air treatment plant, in which the cryogenic liquid is generated in the first operating mode, can be in the form of a cryogenic air separation plant or of an air liquefaction plant.

[0039] A "cryogenic air separation plant" is charged with atmospheric air and has a distillation column system for separating atmospheric air into its physical components, in particular into nitrogen and oxygen. To this end, the feed air is firstly cooled close to its dew point and is then introduced into the distillation column system.

[0040] Methods and apparatuses for the cryogenic separation of air are known for example from Hausen/Linde, Tieftemperaturtechnik, 2nd Edition, 1985, Chapter 4 (pages 281 to 337).

[0041] The distillation column system of the invention can be in the form of a one-column system for nitrogen-oxygen separation, in the form of a two-column system (for example in the form of a conventional Linde double column system) or else in the form of a three-column system or multi-column system. In addition to the columns for nitrogen-oxygen separation, it can have further apparatuses for the recovery of high-purity products and/or other air components, in particular noble gases, for example argon recovery and/or krypton-xenon recovery.

[0042] An "air liquefaction plant" does not contain any distillation column part. Otherwise, the structure thereof corresponds to that of a cryogenic air separation plant, with the delivery of a liquid product. It goes without saying that liquid air can also be generated as a byproduct in a cryogenic air separation plant.

[0043] The cryogenic liquid can be formed by liquefied air and/or liquid nitrogen, or in general terms by a fluid which contains less oxygen than the atmospheric air. It is also possible for a combination of two or more storage fluids of identical or differing composition from the same air treatment plant or from a plurality of air treatment plants to be used within the context of the invention.

[0044] "Nitrogen" is understood here to be both pure or substantially pure nitrogen and a mixture of air gases, the nitrogen content of which is higher than that of the atmospheric air. By way of example, the liquid nitrogen has a nitrogen content of at least 90%, preferably at least 99% (all percentages relate here and hereinbelow to the molar quantity, unless specified otherwise).

[0045] It is preferable that, in the second operating mode too, the high-pressure stream passes into indirect heat exchange with the second liquid refrigeration transfer medium and with the first liquid refrigeration transfer medium at the same superatmospheric pressure in the heat exchanger system (**21**). It is therefore the case that no machine needs to be used for increasing the pressure between the heat exchange with the second refrigeration transfer medium and the heat exchange with the first refrigeration transfer medium.

[0046] The invention also relates to an apparatus for generating energy as per patent claim **12**. A "control device" is to be understood here to be an apparatus which automatically controls the system at least during the first operating mode and during the second operating mode. It is preferably capable of automatically carrying out the transition from the first operating mode to the second operating mode, and vice versa. The apparatus according to the invention may be complemented by apparatus features which correspond to the features of the dependent method claims.

[0047] The invention and further details of the invention will be explained in more detail hereinbelow with reference to exemplary embodiments shown schematically in the drawings, in which:

[0048] FIGS. **1***a* and **1***b* show the basic principle of the invention, respectively in the first and second operating mode,

[0049] FIGS. **2***a* and **2***b* show a detailed illustration of a first embodiment of an air treatment plant which can be used in the invention,

[0050] FIGS. **3***a* and **3***b* show a detailed illustration of a second embodiment of an air treatment plant which can be used in the invention, and

[0051] FIG. **4** shows possible embodiments of the gas expansion unit.

[0052] The overall plant in FIGS. **1***a* and **1***b* consists of three units: an air treatment plant **100**, a liquid tank **200** and a gas expansion unit **300**.

[0053] FIG. **1***a* shows the first operating mode (cheap power phase—generally at night). Here, atmospheric air (AIR) is introduced as feed air into the air treatment plant **100**. A cryogenic liquid **101**, which is formed for example as liquid air, is produced in the air treatment plant. The air treatment plant is operated as a liquefier (in particular as an air liquefier). The cryogenic liquid **101** is introduced into the liquid tank **200**, which is operated at a low pressure LP of less than 2 bar.

[0054] Within the air treatment plant **100**, the feed air is sucked in via a filter **1** by an air compression unit **2** and

compressed to a pressure MP (4 to 8 bar, in particular 5 to 8 bar), cooled in a pre-cooling device **3** and dried in a molecular sieve adsorber station **4** and purified of contaminants such as CO_2 and hydrocarbons. The compressed and purified air is cooled and liquefied in a heat exchanger system **21**. The cryogenic liquid **101** is conducted into the liquid tank **200** (the heat exchanger system **21** is shown only in a very schematic manner in FIGS. **1***a* and **1***b*; further details are shown in FIGS. **2***a* to **3***b*).

[0055] A first cold refrigeration transfer medium store **151** contains liquid ethanol (C_2H_5OH) as the "first refrigeration transfer medium" at a first temperature level T**1** of −110° C. and at a low pressure of less than 2 bar. The liquid first refrigerant is fed via a line **161** at T**1** into a first passage group of the heat exchanger system **21** by means of a first refrigeration transfer medium pump **29**. At the hot end of the heat exchanger system **21**, it is removed again—still in a liquid state—at a second, higher temperature level T**2** of 19° C. and introduced into a first hot refrigeration transfer medium store **152**, which is operated at the second temperature level and likewise at a low pressure of less than 2 bar.

[0056] A second cold refrigeration transfer medium store **153** contains liquid propane (C_3H_8) as the "second refrigeration transfer medium" at a third temperature level T**3** of −180° C. and at a low pressure of less than 2 bar. The liquid second refrigerant is fed via a line **163** at T**3** into a second passage group of the heat exchanger system **21**, that is to say at the cold end thereof, by means of a second refrigeration transfer medium pump **28**. At an intermediate point of the heat exchanger system **21**, it is removed again—still in a liquid state—at a fourth, higher temperature level T**4** of −90° C. and introduced into a second hot refrigeration transfer medium store **154**, which is operated at the fourth temperature level and likewise at a low pressure of less than 2 bar.

[0057] FIG. **1***b* shows the second operating mode (peak power phase—generally during the day). The cryogenic liquid **103** (for example liquid air) is removed from the liquid tank **200**, brought to an elevated pressure of HP**1** (HP**1** is greater than 12 bar, for example approximately 60 bar) in a pump **27**, vaporized in the air treatment plant as a "high-pressure stream" and warmed to approximately ambient temperature and drawn off as a gaseous high-pressure storage fluid **104**.

[0058] The vaporized high-pressure storage fluid **104** is conducted at the pressure HP**1** to the gas expansion unit **300**. The power P**3** which is available at the gas expansion unit **300** in the second operating mode is for example 20 to 70%, preferably 40 to 65%, of the power P**1** which is consumed in the first operating mode by the air treatment plant **100**.

[0059] According to the invention, the heat required for the vaporization of the high-pressure stream is supplied by the two refrigeration transfer media, which are delivered through the same groups of passages of the heat exchanger system **21** as in the first operating mode, but in the reverse direction. In this case, the first refrigerant is conveyed via the pump **29** and a line **162** from the first hot refrigeration transfer medium store **152** to the hot end of the heat exchanger system, and, after cooling from the second temperature level T**2** to the first temperature level T**1**, is introduced via a line **164** into the first cold refrigeration transfer medium store **151**. Analogously thereto, the second refrigerant is conveyed via the pump **28** and the line **164** from the second hot refrigeration transfer medium store **154** to the heat exchanger system **21**, and, after cooling from the fourth temperature level T**4** to the third temperature level T**3**, is introduced via the line **163** into the second cold refrigeration transfer medium store **153**. As a result, the vaporization refrigeration of the cryogenic liquid **103** is stored as sensible heat in the refrigeration transfer media and is available again in the first operating mode for generating cryogenic liquid.

[0060] The production of the cryogenic liquid and the transfer of heat to the refrigeration transfer media on the one hand and the vaporization of the high-pressure stream of cryogenic liquid and the transfer of refrigeration to the refrigeration transfer media on the other hand are carried out in the same process units. The same apparatuses can therefore be used in the first and second operating mode. This gives rise to a relatively low complexity in terms of apparatus.

[0061] In a first embodiment variant, the air compression unit **2** can be switched off during the second operating mode (see FIG. **2***b* at the bottom); in a second embodiment variant (FIG. **3***b* at the bottom), it continues to operate in the second operating mode too and supplies additional compressed air into the line **104** to the gas expansion unit **300**.

[0062] A liquefaction phase (continuous operation in the first operating mode) and a vaporization phase (continuous operation in the second operating mode) can each last for one to ten hours. Over the course of a day, one or more vaporization and respectively liquefaction phases can be carried out. Depending on demand, the air treatment plant can be switched off in the period of time of transition between two such respective phases.

[0063] FIGS. **2***a* and **2***b* show a possible design of the air treatment plant **100** shown in FIG. **1**, which here is in the form of an air liquefier.

[0064] FIG. **2***a* shows in turn the first operating mode (the liquefaction phase). Here, ambient air (AIR) is sucked in via the filter **1** by the air compression unit **2** and compressed to a pressure MP (4 to 8 bar, in particular 5 to 8 bar), cooled in the pre-cooling device **3** and dried in the molecular sieve adsorber station **4** and purified of contaminants such as CO_2 and hydrocarbons. The compressed and purified air at MP is split into a first partial stream and a second partial stream. The first partial stream is conducted to a separate compressor, the circuit compressor **11**, where it is compressed from the pressure MP to a higher pressure HP**2** of 50 to 100 bar, is cooled in an aftercooler to approximately ambient temperature and is then cooled and pseudo-liquefied at HP**2** in the heat exchanger system **21**, is expanded in a throttle valve to the pressure MP and finally is fed in an at least partially liquid state into a phase separating device (separator) **23**. The gaseous fraction from the phase separating device **23** is conducted through the heat exchanger system **21**, where it is warmed, and is guided together with the air from the molecular sieve adsorber station **4** to the suction pipe of the circuit compressor **11**, and thereby forms an air circuit.

[0065] The second partial stream is post-compressed to a still higher pressure MP**2** in a post-compressor **6***a* having an aftercooler and is then cooled in the heat exchanger system **12** from approximately ambient temperature to a first intermediate temperature of 140 to 180 K. In a turbine **5***b*, the second partial stream is expanded to the low pressure LP (LP<2 bar) so as to perform work. The post-compressor **5***a* is driven by the turbine **12***b* via a common shaft. The second partial stream of the feed air which is expanded to perform work is warmed again to ambient temperature in the heat exchanger system **21** and released into the atmosphere (amb). A partial quantity can also be used as regenerating gas for the molecular sieve

adsorber station **4**. The regenerating gas is warmed by steam, an electric heater or natural gas firing (quantity of heat Q).

[0066] Alternatively, the molecular sieve adsorber station **4** is not regenerated at all during the first operating mode, but rather merely in the second operating mode. If the continuous operation in the first operating mode lasts for less than approximately 6 hours, this is readily possible. The molecular sieve adsorber station is then not switched over within an operating mode; it can then also be realized by means of a single adsorber container or by means of a plurality of containers which are operated in parallel.

[0067] The liquid from the phase separating device **23** is subcooled in a subcooler **24** and conducted for the most part (**101**) as a cryogenic liquid into the liquid tank **200**. For the subcooling, use is made of a partial quantity **26** of liquid air, which is removed after the subcooling **24**, is expanded in a throttle valve **25** to the pressure LP and is conducted together with the turbine exhaust gas through the heat exchanger system **21**.

[0068] In the first operating mode, energy P**1**=P**1***a*+P**1***b* is supplied, in the form of the drive powers P**1***a* for the air compression unit and P**1***b* for the circuit compressor, and so too if appropriate is the quantity of heat Q for heating the regenerating gas. No energy is removed (except via the aftercoolers of the compressors), but instead energy is stored in the form of the cryogenic liquid air in the liquid tank **200**.

[0069] The second operating mode will now be described with reference to FIG. **2***b*. Here, the turbine **5***b*, the post-compressor **5***a*, the circuit compressor **11**, the air compression unit **2** and the Joule-Thomson stage (throttle valves, separator **23** and subcooler **24**) are switched off.

[0070] Liquid air (LAIR) **103** is removed from the liquid tank **200**, is brought to the required pressure HP**1** of for example 50 to 80 bar, preferably 40 to 80 bar, in the pump **27**, and is introduced as a high-pressure stream into the heat exchanger system **21**, where it is pseudo-vaporized and warmed to approximately ambient temperature. The pseudo-vaporized air is finally conducted as a gaseous high-pressure storage fluid **104** to the gas expansion unit **300**.

[0071] The two refrigeration transfer medium streams are cooled in countercurrent to the (pseudo-)vaporizing air **103**, as described above in relation to FIG. **1***b*.

[0072] In the second operating mode, no drive energy whatsoever is supplied to the air compression unit (the energy for driving liquid pumps is negligibly low and is therefore not taken into consideration here).

[0073] If the molecular sieve adsorber station **4** is regenerated during the second operating mode, some of the gaseous high-pressure storage fluid **104**, some of the gaseous high-pressure storage fluid heated in the gas expansion unit **300** or some of the exhaust gas of the gas expansion unit **300** can be used as regenerating gas (not shown in the drawing).

[0074] The heat exchanger system **21** of the air treatment plant is used both for the air liquefaction and refrigeration transfer medium heating (in the first operating mode) and for the air vaporization and refrigeration transfer medium cooling (in the second operating mode).

[0075] In the first operating mode as shown in FIG. **3***a*, the second variant of the invention is operated like the first variant (FIG. **1***a*).

[0076] FIG. **3***b* corresponds substantially to FIG. **1***b*, but here the air compression unit **2**, the circuit compressor and the turbine/post-compressor combination **5***a*/**5***b* continue to operate in the second operating mode, too.

[0077] FIG. **4** shows possible embodiments of the gas expansion unit **300**. In embodiments **4***a* and **4***b*, a conventional gas turbine is used for the expansion, the compressed air from the air treatment plant being introduced into the gas turbine upstream of the combustion chamber. The heat of the flue gas at the outlet can be used in a heat recovery steam generator (HRSG) (**4***a*); alternatively, it is used in another way, for example to preheat the compressed air from the air treatment plant (**4***b*).

[0078] In embodiments **4***c* and **4***d*, a converted gas turbine is used for the expansion; in this gas turbine, the compressor part is removed. The compressed air from the air treatment plant is introduced into the combustion chamber of the rest of the gas turbine. The heat of the flue gas can be used in a similar manner to the method with the gas turbine.

[0079] In embodiment **4***e*, the compressed air from the air treatment plant is firstly warmed and expanded in a plurality of successive turbines/turbine stages, the air being additionally warmed between the individual expansion stages. This represents an exemplary embodiment for a gas expansion unit having a hot-gas turbine system which has at least one heater and a hot-gas turbine—in this case, there are respectively two heaters and hot-gas turbines; alternatively, the hot-gas turbine system may also have more than two stages.

[0080] The embodiment variants **4***a* and **4***b* and also **4***c* and **4***d* may be combined with one another.

1. A method for generating electrical energy in a combined system made up of a power plant and an air treatment plant, wherein the power plant has a first gas expansion unit (**300**), which is connected to a generator for generating electrical energy, and the air treatment plant has an air compression unit (**2**), a heat exchanger system (**21**) and a liquid tank (**200**), and wherein in a first operating mode

in the air treatment plant

feed air is compressed in the air compression unit (**2**) and cooled in the heat exchanger system (**21**),

a storage fluid is produced from the compressed and cooled feed air,

the storage fluid is stored as a cryogenic liquid (**101**) in the liquid tank (**200**),

a stream of a first refrigeration transfer medium is introduced in the liquid state into the heat exchanger system (**21**), where it is warmed from a first temperature level T**1** to a second temperature level T**2**, and

a stream of a second liquid refrigeration transfer medium is introduced in the liquid state into the heat exchanger system (**21**), where it is warmed from a third temperature level T**3** to a fourth temperature level T**4**,

and in a second operating mode

cryogenic liquid (**103**) is taken from the liquid tank (**200**) and vaporized or pseudo-vaporized and warmed as a high-pressure stream in the heat exchanger system (**21**) in indirect heat exchange, and the gaseous high-pressure storage fluid (**104**) generated in the process is expanded in the gas expansion unit (**300**),

a stream of the first refrigeration transfer medium is introduced in the liquid state into the heat exchanger system (**21**), where it is cooled from the second temperature level T**2** to the first temperature level T**1**, and

a stream of the second liquid refrigeration transfer medium is introduced in the liquid state into the heat exchanger system (**21**), where it is cooled from the fourth temperature level T**4** to the third temperature level T**3**, and

the (pseudo-)vaporization of the cryogenic liquid (**103**) is carried out, characterized in that,

in the first operating mode, the feed air compressed in the air compression unit (**2**) passes into indirect heat exchange with the first liquid refrigeration transfer medium and with the second liquid refrigeration transfer medium at the same pressure in the heat exchanger system (**21**).

2. The method as claimed in claim **1**, characterized in that the warming of the first refrigeration transfer medium in the first operating mode and the cooling of the first refrigeration transfer medium in the second operating mode are carried out in the same groups of passages of the heat exchanger system (**21**).

3. The method as claimed in claim **1**, characterized in that the warming of the second refrigeration transfer medium in the first operating mode and the cooling of the second refrigeration transfer medium in the second operating mode are carried out in the same groups of passages of the heat exchanger system (**21**).

4. The method as claimed in claim **1**, characterized in that the first temperature level is lower than the fourth temperature level, in particular is more than 18 K lower.

5. The method as claimed in claim **1**, characterized in that feed air is also compressed in the air compression unit (**2**) in the second operating mode.)

6. The method as claimed in claim **1** characterized in that the power plant has a gas turbine system with a combustion chamber, a gas turbine expander and a generator, and at least some of the gaseous high-pressure storage fluid (**104**) is expanded in the gas turbine expander of a gas turbine system, the storage fluid (**104**) being fed to the gas turbine system downstream of the (pseudo-)vaporization (**21**).

7. The method as claimed in claim **1**, characterized in that the gas expansion unit has a hot-gas turbine system having at least one heater and a hot-gas turbine.

8. The method as claimed in claim **6**, characterized in that the gaseous high-pressure storage fluid is expanded in two steps, the first step being carried out as a work-performing expansion in the hot-gas turbine system and the second step being carried out in the gas turbine system, the gaseous high-pressure storage fluid being fed to the hot-gas turbine system, where it is expanded to an intermediate pressure, and a gaseous intermediate-pressure storage fluid being taken from the hot-gas turbine system and finally being fed to the gas turbine system.

9. The method as claimed in claim **1**, characterized in that the air treatment plant (**2**) is in the form of a cryogenic air separation plant or of an air liquefaction plant.

10. The method as claimed in claim **1**, characterized in that the cryogenic liquid (**3**) is formed by liquefied air or liquid nitrogen.

11. The method as claimed in claim **1**, characterized in that, in the second operating mode, the high-pressure stream passes into indirect heat exchange with the second liquid refrigeration transfer medium and with the first liquid refrigeration transfer medium at the same superatmospheric pressure in the heat exchanger system (**21**).

12. An apparatus for generating electrical energy having a combined system made up of a power plant and an air treatment plant, wherein the power plant has a first gas expansion unit (**300**), which is connected to a generator for generating electrical energy, and the air treatment plant has an air compression unit (**2**), a heat exchanger system (**12**) and a liquid tank (**200**), and wherein the apparatus has a control device and also pipelines and control elements, with the aid of which it can be operated in a first and in a second operating mode, wherein

in a first operating mode

in the air treatment plant

feed air is compressed in the air compression unit (**2**) and cooled in the heat exchanger system (**12**),

a storage fluid is produced from the compressed and cooled feed air,

the storage fluid is stored as a cryogenic liquid (**101**) in the liquid tank (**200**),

a stream of a first refrigeration transfer medium is introduced in the liquid state into the heat exchanger system (**21**), where it is warmed from a first temperature level T**1** to a second temperature level T**2**, and

a stream of a second liquid refrigeration transfer medium is introduced in the liquid state into the heat exchanger system (**21**), where it is warmed from a third temperature level T**3** to a fourth temperature level T**4**, and in a second operating mode

cryogenic liquid (**103**) is taken from the liquid tank (**200**) and vaporized or pseudo-vaporized as a high-pressure stream in the heat exchanger system (**21**) at superatmospheric pressure, and the gaseous high-pressure storage fluid (**104**) generated in the process is expanded in the gas expansion unit (**300**),

a stream of the first refrigeration transfer medium is introduced in the liquid state into the heat exchanger system (**21**), where it is cooled from the second temperature level T**2** to the first temperature level T**1**, and

a stream of the second liquid refrigeration transfer medium is introduced in the liquid state into the heat exchanger system (**21**), where it is cooled from the fourth temperature level T**4** to the third temperature level T**3**,

characterized in that

the control device and also the pipelines and the control elements are formed in such a way that, in the first operating mode, the feed air compressed in the air compression unit (**2**) passes into indirect heat exchange with the first liquid refrigeration transfer medium and with the second liquid refrigeration transfer medium at the same pressure in the heat exchanger system (**21**).

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