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Title of the invention

A method for liquefying a natural gas and for recovery of possible liquids of the natural gas comprising two semi-open refrigerant cycles with natural gas and a single refrigerant cycle closed with refrigerant gas

Background of the invention

[0001] The present invention relates to the general field of the liquefaction of natural gas based mainly on methane to produce LNG, for Liquefied Natural Gas, also called LNG in English (for « Liquefied Natural Gas »).

[0002] A particular but non-limiting field of application of the invention is that of floating natural gas liquefaction installations, called FLNG in English (for “Floating Liquefaction of Natural Gas”), which make it possible to carry out offshore liquefaction of natural gas, on a ship or on any other floating medium at sea.

[0003] The predominantly methane-based natural gas that is used to produce LNG is either a by-product from oil fields, that is to say produced in combination with crude oil, in which case it is in low or medium quantity, or a major product from gas fields.

[0004] When natural gas is combined in small quantities with crude oil, it is generally treated and separated then reinjected into oil wells, exported by pipeline and/or used on site, in particular as fuel to supply electric power generators, ovens or boilers.

[0005] When natural gas comes from gas fields and produced in high quantities, it is in contrast tried to transport it so that it can be used in regions other than those in which it was produced. To this end, natural gas can be transported in the tanks of specialized transport vessels (called "LNG carriers") in the form of cryogenic liquid (at a temperature of the order of -160°C) and at a pressure close to ambient atmospheric pressure.

[0006] The liquefaction of natural gas for transport is generally carried out near the gas production site and requires large-scale installations and considerable amounts of mechanical

energy for production capacities of up to several million tonnes per year. The mechanical energy required for the liquefaction process can be produced at the site of the liquefaction plant using part of the natural gas as fuel.

[0007] Natural gas must undergo a treatment prior to its liquefaction in order to extract the acid gases (in particular carbon dioxide), water (to prevent it from freezing in the liquefaction installation), mercury (to avoid the risk of degradation of the aluminium equipment of the liquefaction plant) and part of the natural gas liquids, also called NGLs in English (for “Natural Gas Liquids”). The NGLs include all the hydrocarbons heavier than methane present in natural gas and liable to be condensed. The NGLs include in particular ethane, LPGs (propane and butanes) for Liquefied Petroleum Gas, also called LPGs in English (for “Liquefied Petroleum Gas”), pentanes and hydrocarbons heavier than the pentanes present in the natural gas. Among these hydrocarbons, it is in particular critical to extract benzene, most of the pentanes and other heavier hydrocarbons upstream from the liquefaction installations, in order to prevent them from freezing in the liquefaction installation. In addition, the extraction of LPG and ethane may also be necessary for the LNG to meet the commercial calorific value specification or to ensure commercial production of these products.

[0008] The extraction of NGLs is either integrated into the natural gas liquefaction installation, or carried out in a dedicated unit upstream of the liquefaction installation. In the first case, this extraction is generally carried out at a relatively high pressure (of the order of 4 to 5 MPa) while in the second case, it is most of the time carried out at a lower pressure (of the order of from 2 to 4 MPa).

[0009] An extraction of NGLs integrated with the liquefaction of natural gas as described for example in the publication US Pat. No. 4,430,103 has the advantage of being simple. However, this type of process only operates at a pressure lower than the critical pressure of the gas to be liquefied, which adversely affects the efficiency of the liquefaction. In addition, this type of process typically performs the separation of natural gas and NGLs at a pressure of the order of 4 to 5 MPa. However, at these pressures, the selectivity of the extraction of NGLs is low. Indeed, a significant portion of methane is extracted at the same time as the NGLs. Downstream treatment is then generally necessary to discharge this methane.

[0010] Moreover, at a pressure of the order of 4 to 5 MPa, the densities of the liquid and of the natural gas are relatively close, which makes the design and the operation of separator flasks and distillation columns difficult (in particular in as part of an application on a floating medium).

[0011] An extraction of NGLs at a pressure of the order of 2 to 4 MPa upstream of the liquefaction installation in a dedicated unit as described for example in the publication US Pat. No. 4,157,904 makes it possible to achieve high recovery rates of NGLs with a good selectivity (i.e. little methane extracted). It also makes it possible to ensure that the liquefaction feed gas is at the optimum pressure for liquefaction (typically at least equivalent to the critical pressure) by the use of a dedicated re-compressor. On the other hand, such an extraction of NGLs requires numerous and complex equipment and requires significant amounts of mechanical energy for the recompression of natural gas.

[0012] Thus, the way in which NGLs are extracted has a significant impact on the cost and degree of complexity of the liquefaction plant, on the performance of the liquefaction, and on the energy efficiency of the liquefaction plant as a whole.

[0013] Different natural gas liquefaction processes have been developed in order to optimize their overall energy efficiency. In principle, these liquefaction processes are typically based on mechanical refrigeration of natural gas obtained by virtue of one or more thermodynamic refrigeration cycles providing the thermal power necessary for cooling and liquefaction of natural gas. In each thermodynamic cycle implemented by these processes, the compressed refrigerant (in the form of gas) is cooled (and possibly condensed) by a thermal source having a temperature higher than that of the refrigerated fluid and called "hot source" (water, air, another refrigeration cycle) then further cooled by a stream of cold gas generated by the thermodynamic cycle itself before being expanded. The low temperature cold refrigerant stream resulting from this expansion is used to cool the natural gas and pre-cool the refrigerant. The low pressure gaseous refrigerant is again compressed to its original pressure level (via compressors driven by gas turbines, steam turbines or electric motors).

[0014] During these thermodynamic refrigeration cycles, the power necessary for the refrigeration and liquefaction of natural gas can be supplied either by the vaporization and

heating of a liquid refrigerant, most of the refrigeration heat being produced by the latent heat brought into play during the change of state, either by the heating of a cold refrigerant in the form of gas. In the case of a refrigerant gas, the temperature of the refrigerant is typically lowered by pressure reduction through an expansion turbine (in English « gas expander »). The cooling effect produced by the refrigerant is mainly in the form of sensible heat.

[0015] In the case of a liquid refrigerant, the temperature of the refrigerant is generally lowered by expansion through a valve and/or a liquid expansion turbine (in English « liquid expander »). The cooling effect produced by the refrigerant is mainly in the form of latent heat (and, to a lesser extent, in the form of sensible heat). As latent heat is much higher than sensible heat, the refrigerant stream rates which are necessary to obtain the same refrigeration capacity are higher for thermodynamic cycles using a refrigerant in the form of gas than for thermodynamic cycles using a refrigerant in liquid form.

[0016] Thus, for the same liquefaction capacity, thermodynamic refrigeration cycles using a gas as refrigerant require higher capacity refrigeration compressors and larger diameter pipes than for thermodynamic refrigeration cycles using a liquid as refrigerant. Thermodynamic cycles with gaseous refrigerant are also generally less efficient than thermodynamic cycles with liquid refrigerant, in particular because the temperature difference between the fluid undergoing refrigeration and the refrigerant fluid is on average higher for a cycle with gaseous refrigerant, which contributes to increasing the losses of efficiency by irreversibility.

[0017] On the other hand, thermodynamic cycles of refrigeration with liquid refrigerant implement mass refrigerant inventories higher than thermodynamic cycles with gaseous refrigerant. When the refrigerant fluids used are flammable or toxic, the liquid refrigerant thermodynamic cycles have a lower level of intrinsic safety than gaseous refrigerant processes, especially when comparing liquid refrigerant thermodynamic cycles using hydrocarbons as refrigerant with thermodynamic cycles which use an inert gas such as nitrogen as refrigerant. This point is particularly critical in an environment where a large amount of equipment is concentrated in a small space and in particular on an offshore installation. Thermodynamic refrigeration cycles using liquid refrigerants are thus efficient but have a certain number of drawbacks, in particular for an offshore application on a floating support.

[0018] Different liquefaction processes using thermodynamic refrigeration cycles with gaseous refrigerant have been proposed. For example, documents US 5916260 WO 2005/071333, WO 2009/130466, WO 2012/175889 WO 2013/057314, and FR2317609 are known for double or triple expansion of nitrogen liquefaction processes in which the heated nitrogen at the outlet of a heat exchanger is compressed. When the compressors discharge, the nitrogen is cooled and expanded by turbines in order to be used to cool and liquefy natural gas.

[0019] Such nitrogen expansion liquefaction processes have certain advantages in terms of simplicity, intrinsic safety and robustness which make them particularly suitable for application on an offshore floating support. However, these methods are also inefficient. Thus, a process using liquid refrigerants typically produces around 30% more LNG than a process with double nitrogen expansion (at equivalent mechanical power expended).

[0020] Also known from documents WO 2007/021351 and US 6,412,302 are natural gas liquefaction processes combining natural gas and nitrogen expansions. These methods make it possible to improve the efficiency of the liquefaction but do not integrate the extraction of the NGLs into the liquefaction. However, this extraction may require numerous and complex equipment and/or have a negative impact on the efficiency of the liquefaction.

[0021] Finally, documents US 7,225,636 and WO 2009/017414 are known of natural gas liquefaction processes combining refrigeration cycles for the liquefaction of natural gas by gas expansion turbine and extraction of NGLs. However, these methods have a number of disadvantages. In particular, in these two documents, the extraction of the NGLs takes place at a relatively high pressure which induces a low separation selectivity, while the liquefaction of natural gas takes place at low pressure (under the critical pressure), which interferes with its effectiveness.

Purpose and summary of the invention

[0022] The main aim of the present invention is therefore to overcome such drawbacks by proposing a liquefaction process using thermodynamic cycles with gaseous refrigerant and

having a higher efficiency than the liquefaction processes of the prior art while proposing a simple and compact method of extraction of any NGLs, which is integrated into the liquefaction process and which offers better overall energy optimization than the processes of the prior art.

[0023] In accordance with the invention, this object is achieved by means of a process for liquefying a natural gas according to claim 1 comprising a hydrocarbon mixture, mainly methane, the process comprising:

a) a first cycle semi-open to the natural gas in which, successively:

a natural gas feed stream at a pressure P_0 pre-treated to extract therefrom acid gases, water, and mercury is mixed with a natural gas stream, expanded to a pressure P_1 and its temperature lowered to a temperature T_1 by means of an expansion turbine at room temperature so as to obtain a condensation of possible natural gas liquids contained in the natural gas,

the possible natural gas liquids that have been condensed are separated in a main separator from the natural gas feed stream, the latter then passing through a main cryogenic heat exchanger in order to form a first stream of natural gas contributing by heat exchange, on the one hand to the pre-cooling of a main stream of natural gas streaming counter-current through the main cryogenic heat exchanger, and on the other hand, to the cooling of an initial stream of refrigerant gas streaming counter-current in the main cryogenic heat exchanger,

at the outlet of the main cryogenic heat exchanger, the first natural gas stream which is at a temperature T_2 greater than T_1 and close to the temperature of a hot source, is compressed at a pressure P_2 by means of a compressor driven by the room temperature expansion turbine before being admitted to the suction of a natural gas compressor to be further compressed therein at a pressure P_3 greater than P_2 and form a second stream of natural gas,

the second natural gas stream at the discharge of the natural gas compressor is partly expanded and mixed with the natural gas feed stream upstream of the room temperature expansion turbine, and partly forms the main stream of natural gas,

a fraction of this main stream of natural gas passes through the main cryogenic heat exchanger in order to be cooled to a temperature T_3 low enough to allow the liquefaction of the natural gas;

b) a second refrigerant cycle semi-open to the natural gas in which, successively:

another fraction of the main stream of natural gas is extracted from the main cryogenic heat exchanger at a temperature T_4 greater than T_3 to be directed to an intermediate expansion turbine so that its temperature is lowered by expansion to a temperature T_5 lower than T_4 and form a third stream of natural gas,

the third natural gas stream is reintroduced into the main cryogenic heat exchanger to cool by heat-exchange the main natural gas stream and the initial stream of refrigerant gas counter-current circulating into the main cryogenic heat exchanger,

at the outlet of the main cryogenic heat exchanger, the third natural gas stream which is at a temperature T_6 close to the temperature of the hot source is directed to a compressor driven by the intermediate expansion turbine to be compressed therein and then it is cooled before being mixed with the first stream of natural gas upstream of the natural gas compressor;

c) a refrigerant cycle closed to the refrigerant gas in which, successively:

an initial stream of refrigerant gas with a temperature T_7 close to the temperature of the hot source and previously compressed by a refrigerant gas compressor is circulated in the main cryogenic heat exchanger to be pre-cooled therein,

at the outlet of the main cryogenic heat exchanger, the initial stream of refrigerant gas which is at a temperature T_8 lower than T_7 is directed to a low temperature expansion turbine so that its temperature is lowered by expansion to a temperature T_9 lower than T_8 , the first stream of refrigerant gas thus formed being reintroduced into the main cryogenic heat exchanger to contribute to the cooling of the main stream of natural gas and the initial stream of refrigerant gas;

at the outlet of the main cryogenic heat exchanger, the first stream of refrigerant gas which is at a temperature T_{10} close to the temperature of the hot source is directed to a compressor driven by the low temperature expansion turbine to be compressed therein before being cooled and then directed to the suction of the refrigerant gas compressor.

[0024] The liquefaction process according to the invention comprises two semi-open refrigerant cycles with natural gas and a single closed refrigerant cycle with refrigerant gas. The function of the first semi-open refrigerant cycle using natural gas is to extract the heavy natural gas liquids (NGLs) that may be present in the natural gas to avoid freezing problems in the cold section of the liquefaction plant, and to pre-cool natural gas and refrigerant gas. The function of the second semi-open refrigerant cycle with natural gas is to contribute to the pre-cooling of the natural gas and the refrigerant gas as well as to the liquefaction of the natural

gas. The function of the refrigerant cycle closed to refrigerant gas is to sub-cool the liquefied natural gas and to supply additional refrigeration power to the other two cycles. The refrigerant gas used is typically nitrogen.

[0025] It has been calculated that the process according to the invention exhibits a ratio of mechanical power consumed per tonne of LNG produced for equivalent conditions of the order of 15% lower than a process with two refrigerant cycles using nitrogen, 10 % lower than a three-cycle nitrogen refrigerant process, and 8% lower than a one-cycle natural gas refrigerant and two nitrogen refrigerant cycle process when these processes are combined with a unit of extraction of NGL upstream of the liquefaction requiring recompression of the gas (this recompression power being taken into account in the comparison). The power consumed per tonne of LNG produced by the process according to the invention is thus lower than for the processes known from the prior art, which shows a higher efficiency for this process.

[0026] The process according to the invention integrates the liquefaction with the extraction of heavy natural gas liquids (NGLs), which improves the overall energy efficiency of the natural gas liquefaction plant and eliminates the need to resort to installations dedicated to this extraction. This simplifies the natural gas pre-treatment process. In addition, the extraction being carried out at low pressure, few light hydrocarbons (in particular methane) are entrained during this extraction process, which makes it possible to treat the heavy NGLs using a process which is simple to implement.

[0027] The single refrigerant gas cycle of the process according to the invention is closed. Thus, the only additional refrigerant gas that is necessary can be easily produced (in this case when the refrigerant gas mainly comprises nitrogen). In particular, no dedicated unit is required for the import, production, treatment or storage of liquid hydrocarbons used as refrigerant. The implementation of the method according to the invention is thus greatly facilitated.

[0028] The method according to the invention has a high level of intrinsic safety. Indeed, the mass inventories of hydrocarbons are limited (in particular compared to a process using

hydrocarbons in liquid form as coolant). The implementation of the method according to the invention is thereby facilitated.

[0029] Finally, the process is particularly suitable for an installation for the liquefaction of natural gas at sea, such as for example on board an FLNG, because of its high level of intrinsic safety and the fact that it does not require storage of refrigerants.

[0030] According to a variant known as "series recompression", during the second refrigerant cycle semi-open to the natural gas, the natural gas stream at the outlet of the compressor driven by the intermediate expansion turbine is cooled and then mixed to the first natural gas stream before being directed to the inlet of the compressor driven by the room temperature expansion turbine. This variant makes it possible to achieve staged compression of the natural gas so as to make the latter more efficient.

[0031] According to a variant known as "complementary pre-cooling by auxiliary refrigerant cycle", during the first semi-open refrigerant cycle with the natural gas, the natural gas feed stream at the inlet of the room temperature expansion turbine is further cooled in an auxiliary heat exchanger. In this variant, an auxiliary refrigeration cycle provides the refrigeration power necessary for the operation of the auxiliary heat exchanger. As a result of this arrangement, the temperature in the main separator is lowered, which makes it possible to obtain better recovery of the NGLs.

[0032] According to a variant known as "absorption of NGL by sub-cooled reflux", during the second refrigerant cycle semi-open to the natural gas, the third natural gas stream at the exhaust of the intermediate expansion turbine is directed to an auxiliary separator at the outlet of which the stream of natural gas is reintroduced into the main cryogenic heat exchanger, the stream of liquids of the natural gas at the outlet of the auxiliary separator being pumped in whole or in part to the main separator to contribute to the absorption of liquids from the natural gas. The contact between the natural gas to be treated and the sub-cooled reflux can for example be carried out against the current. For this purpose, the main separator can be equipped with a packing bed. With this variant, it is possible to easily treat light gases with a high content of aromatic compounds (for example benzene) or to extract LPGs with a high recovery rate (for example to ensure industrial production of LPGs).

[0033] According to a variant known as “absorption of NGL by LNG reflux”, during the first semi-open refrigerant cycle with the natural gas, a portion of the fraction of main natural gas stream which passes through the main cryogenic heat exchanger in order to be cooled therein is extracted from said main cryogenic heat exchanger at a temperature T11 greater than the temperature T3 to be directed to the main separator so as to contribute to the absorption of liquids from the natural gas. The contact between the natural gas to be treated and the LNG reflux can for example be carried out against the current. For this purpose, the main separator can be equipped with a packing bed. With this variant, it is possible to treat light gases with a content of aromatic compounds (for example benzene) or to extract in particular LPGs with a high recovery rate and ethane.

[0034] During the first semi-open refrigerant cycle with natural gas, the natural gas feed stream is advantageously mixed with lighter natural gas coming from the discharge of the natural gas compressor before being expanded in the turbine at room temperature without pre-cooling in the main cryogenic exchanger, which makes it possible to efficiently produce a cold stream ensuring the pre-cooling of the natural gas and the refrigerant gas and to extract any NGLs with excellent selectivity.

[0035] During the first semi-open refrigerant cycle with the natural gas, the natural gas feed stream at the exhaust of the expansion turbine at room temperature is introduced into the main separator at the outlet of which a stream of natural gas liquids is recovered. In this case, a fraction of the liquid stream of the recovered natural gas is reheated and partially vaporized in order to facilitate its downstream processing.

[0036] According to an advantageous arrangement, the pressure of the main natural gas stream is greater than the critical pressure of natural gas, which makes it possible to maximize the efficiency of the liquefaction and ensures that the liquefaction takes place without a phase change.

[0037] The subject of the invention is also a natural gas liquefaction installation according to claim 14 for implementing the method as defined above, the installation comprising an expansion turbine at ambient temperature intended to receive a feed stream of natural gas as

well as part of a second stream of natural gas coming from the discharge of a natural gas compressor and having an exhaust connected to an inlet of a main separator, a main cryogenic heat exchanger intended to receive the streams natural gas and refrigerant gas, a compressor driven by the expansion turbine at ambient temperature intended to receive a first stream of natural gas from the main separator and having an outlet connected to the suction of the natural gas compressor, a turbine of intermediate temperature expansion designed to receive part of a main stream of natural gas coming from the discharge of the natural gas compressor and connected at the inlet and outlet to the main cryogenic heat exchanger, a compressor driven by the expansion turbine at intermediate temperature intended to receive a third stream of natural gas coming from the main cryogenic heat exchanger, an expansion turbine at low temperature for refrigerant gas connected in inlet and outlet to the main cryogenic heat exchanger, and a compressor driven by the low temperature expansion turbine and having an outlet connected to the suction of a refrigerant gas compressor.

[0038] Preferably, the natural gas compressor and the refrigerant gas compressor are driven by a same driving machine providing the power required for the pressure increase of the natural gas to be liquefied as well as the compression of circulating fluids in the three refrigerant cycles. The mechanical power consumption required for these functions is thus optimized so as to maximize LNG production while minimizing the number of equipment.

[0039] Also preferably, the natural gas compressor is downstream of the compressors driven by the room temperature expansion turbine and the intermediate temperature expansion turbine, and wherein the refrigerant gas compressor is downstream of the compressor driven by the low temperature expansion turbine.

Brief description of the drawings

[0040] Other characteristics and advantages of the present invention will emerge from the description given below, with reference to the appended drawings which illustrate exemplary embodiments thereof without any limiting nature. In the figures:

- FIG. 1 schematically represents an example of implementation of the liquefaction process according to the invention;

- FIG. 2 represents a variant of the implementation of the liquefaction process according to the invention known as “serial recompression”;
- FIG. 3 represents another variant of the implementation of the liquefaction process according to the invention known as “complementary pre-cooling by an auxiliary refrigerant cycle”;
- FIG. 4 represents another variant of the implementation of the liquefaction process according to the invention known as “absorption of NGL by sub-cooled reflux”; and
- FIG. 5 represents another variant implementation of the liquefaction process according to the invention known as “absorption of NGL by reflux of LNG”.

Detailed description of the invention

[0041] The liquefaction process according to the invention applies in particular (but not exclusively) to natural gas coming from gas fields. Typically, this natural gas mainly comprises methane and is found in combination with other gases, mainly C2, C3, C4, C5, C6 hydrocarbons, acid gases, water, and inert gases including nitrogen, as well as various impurities including mercury.

[0042] FIG. 1 represents an example of installation 2 for the implementation of the natural gas liquefaction process according to the invention.

[0043] In substance, the liquefaction process according to the invention uses three thermodynamic refrigeration cycles, namely two refrigerant cycles semi-open to natural gas and a single refrigerant cycle closed to refrigerant gas.

[0044] Furthermore, the process according to the invention preferably uses as refrigerant gas a gas comprising mainly nitrogen, which makes the process particularly suitable for offshore implementation, typically on a floating natural gas liquefaction installation (called in English FLNG for “Floating Liquefaction of Natural Gas”).

[0045] As shown in Figure 1, this liquefaction installation 2 requires only one main cryogenic heat exchanger 4, the latter possibly consisting of an assembly of brazed aluminium heat exchangers which is installed in a cold box (called "cold box" in English).

[0046] The liquefaction installation 2 according to the invention also requires three turbo-expander (called "turbo-expander" in English), namely a turbo expander at ambient temperature 6 dedicated to natural gas, a turbo expander at intermediate temperature 8 dedicated to natural gas, and a turbo expander at low temperature 10 dedicated to the refrigerant gas.

[0047] In a known manner, a turbo expander is a rotating machine which is composed of a gas expansion turbine (here respectively an expansion turbine at ambient temperature 6a, an expansion turbine at intermediate temperature 8a, and a expansion turbine at low-temperature 10a and a gas compressor (here respectively a compressor 6b, a compressor 8b, and a compressor 10b) driven by the gas expansion turbine.

[0048] The liquefaction installation 2 according to the invention also comprises a natural gas compressor 12 and a refrigerant gas compressor 14, these two compressors 12, 14 preferably being driven by the same drive machine ME, for example a turbine with gas supplying the power necessary for increasing the pressure of the natural gas to be liquefied as well as for compressing the fluids circulating in the three refrigerant cycles.

[0049] As will be detailed later, the natural gas compressor fulfils a threefold function: to pressurize and ensure the circulation of natural gas in such a way as to provide sufficient refrigeration power to aid in the cooling and liquefaction of natural gas and refrigerant gas, re-compress the natural gas which has been expanded for the extraction of heavy NGLs, and ensure that the natural gas to be liquefied is at the optimum pressure to maximize the efficiency of the liquefaction.

[0050] As for the refrigerant gas compressor, its function is to pressurize and ensure the circulation of the refrigerant gas so as to obtain the refrigeration power necessary to contribute to the cooling of the refrigerant gas, to contribute to the pre-cooling and liquefaction of natural gas and ensure the sub-cooling of natural gas.

[0051] The liquefaction installation 2 also comprises a main separator 16 intended for the

separation of the NGLs possibly contained in the natural gas, and a balloon 18 intended to allow a separation between the final flash gases and the liquefied natural gas (LNG).

[0052] The various stages of the natural gas liquefaction process according to the invention will now be described.

[0053] Prior to the first semi-open refrigerant cycle with natural gas, the natural gas undergoes a pre-treatment intended to make it suitable for liquefaction. This pre-treatment comprises in particular a treatment for extracting acid gases (including carbon dioxide) from natural gas, these acid gases being able in particular to freeze in the liquefaction installation. The pre-treatment also includes a dehydration treatment to extract water from natural gas and a demercurization treatment, as the mercury risks degrading the aluminium equipment of the liquefaction plant (including the main cryogenic heat exchanger 4).

[0054] The natural gas feed stream F-0 leaves this preliminary pre-treatment phase, typically at a pressure P0 of between 5 and 10 MPa and a temperature T0 close (namely here slightly higher) to the temperature of the hot source. By “hot source” is meant here the thermal source which is used to cool the non-cryogenic streams of the liquefaction process. This hot source can typically be ambient air, seawater, fresh water cooled by seawater, a fluid cooled by an auxiliary refrigerant cycle or a combination of several of these sources.

[0055] This stream F-0 is mixed with the stream of natural gas F-2-1 coming from the liquefaction plant (and described later) and supplies the first semi-open refrigerant cycle with natural gas.

[0056] As indicated above, this first semi-open refrigerant cycle with natural gas has the function of extracting the heavy NGLs possibly present in the natural gas, and of pre-cooling the natural gas and the refrigerant gas.

[0057] To this end, the natural gas feed stream F-0 (combined with the natural gas stream F-2-1 described later) passes through the expansion turbine at ambient temperature 6a at the exhaust (i.e. outlet) from which its pressure P1 is lowered to a pressure between 1 and 3 MPa and its temperature T1 is lowered to a temperature between -40°C and -60°C. This phase of

expansion of the natural gas supply stream leads to condensation of any heavy NGLs (for “Natural Gas Liquids”) contained in the natural gas.

[0058] By heavy NGLs, one understands here the main part of the hydrocarbons in C5 (pentanes), C6 (hexanes, benzene) and more which are contained in natural gas, as well as a more restricted and variable portion of ethane, propane, and of butanes and a very limited portion of methane.

[0059] With the condensation of heavy NGLs, the stream of natural gas at the exhaust of the expansion turbine at room temperature 6a is directed to the inlet of the main separator 16. At the outlet of the main separator 16, the stream of natural gas F-HL liquids is reheated, for example by circulating in the main cryogenic heat exchanger 4 (as shown in the figure) or by passing through a dedicated NGLs reboiler, then it is sent to a NGLs processing unit 20. After being reheated, the stream of F-HL natural gas liquids is two-phase and can either be sent directly to the NGLs processing unit 20 (as shown in the figure) or be subjected to gas-liquid separation, the evaporated gases being returned to the main separator 16.

[0060] The NGLs treatment unit 20 is a unit which makes it possible to treat heavy NGLs, and in particular to separate the butanes and lighter hydrocarbons from the pentanes and heavier hydrocarbons to form at the outlet a stream of light natural gas liquids F-G (also referred to as F-G light NGLs stream) and a natural gas gasoline stream. At the outlet of the NGLs treatment unit, this stream of light F-G NGLs which mainly comprises ethane, propane, and butanes is intended to be reinjected into the gas to be liquefied if this is compatible with the LNG specification concerned (or recovered outside the liquefaction installation if this is not the case).

[0061] Furthermore, a fraction F-HL-1 of the stream of heavy natural gas liquids F-HL can be directed to a NGLs cooler 19 to provide the thermal power necessary for the operation of this exchanger. In particular, the stream of light natural gas liquids F-G from the NGLs processing unit 20 is cooled in the NGLs cooler 19. An F-G-1 fraction of the cooled F-G light NGLs stream is reinjected into the main separator 16.

[0062] By controlling the reinjection rate of this F-G-1 stream into the main separator, it is thus

possible to improve the extraction of heavy NGLs and in particular to reduce the residual quantity of benzene and heavy hydrocarbons in the outlet gas of the main separator.

[0063] The fraction of the cooled light NGLs F-G stream which is not reinjected into the main separator 16 is reinjected into the main natural gas stream F-P, downstream of the withdrawal supplying the intermediate temperature turbine 8a (mentioned later).

[0064] It will be noted that the reinjection of the F-G-1 fraction of the cooled light F-G NGLs stream into the main separator 16 is not necessary if the quantities of benzene and C5 hydrocarbons and more in the natural gas feed stream are weak. It will also be noted that the cooling of the stream of light F-G NGLs can be carried out directly in the main cryogenic exchanger 4 if a dedicated exchanger for this purpose is not provided.

[0065] Finally, it will be noted that the injection of the stream of light F-G NGLs can be carried out either concurrently or counter-currently. In the case where the stream of light F-G NGLs is reinjected against the current into the main separator 16, the latter may optionally be equipped with a packing bed to improve the efficiency of the extraction of the NGLs.

[0066] On leaving the main separator 16, the stream of natural gas freed from heavy hydrocarbons (gas residue) is at an acceptable temperature to ensure pre-cooling of the gas to be liquefied and of the refrigerant gas. To this end, this gas residue forms a first stream of natural gas F-1 which passes through the main cryogenic heat exchanger.

[0067] When it passes through the main cryogenic heat exchanger, the first stream of natural gas F-1 cools by heat exchange, on the one hand a main stream of natural gas F-P streaming counter-currently in the main cryogenic heat exchanger, and on the other hand the initial stream of refrigerant gas G-0 (mentioned later) circulating in counter-current in the main cryogenic heat exchanger.

[0068] At the outlet of the main cryogenic heat exchanger, the first stream of natural gas F-1 is at a temperature T2 greater than T1 and close to the temperature of the hot source. It is sent to the compressor 6b driven by the expansion turbine at ambient temperature 6a to be compressed there to a pressure P2, typically between 2 and 4 MPa.

[0069] At the discharge (i.e. at the outlet) of the compressor 6b, the natural gas stream passes through a natural gas cooler 21 then is admitted to the suction (i.e. at the inlet) of the natural gas compressor 12 in order to be further compressed there to a pressure P3 greater than P2 and P0 (and preferably greater than the critical pressure of natural gas) and form at the outlet a second stream of natural gas F-2. Typically, the pressure P3 may be between 6 and 10 MPa.

[0070] In this natural gas compressor 12, the natural gas stream can be compressed in two successive compression phases between which the natural gas stream can be cooled by a natural gas cooler 22.

[0071] The second natural gas stream F-2 passes through another natural gas cooler 24 and is then separated into two stream fractions: a stream fraction F-2-1 is expanded and mixed with the gas feed stream natural gas F-0 upstream of the expansion turbine at ambient temperature 6a (as described above), and the remaining fraction of this stream forms the main stream of natural gas F-P which passes through the main cryogenic heat exchanger 4.

[0072] It will be noted that the expansion of the stream F-2-1 can be done either by means of a simple control valve 23 (as shown in the figure), or by means of an expansion turbine.

[0073] A fraction of this main stream of natural gas F-P passes through the main cryogenic heat exchanger in order to be cooled there to a temperature T3 (typically between -140°C and -160°C) sufficiently low to ensure liquefaction of natural gas.

[0074] Another fraction of the main stream of natural gas F-P is subjected to a second semi-open natural gas cycle. The objective of this second cycle is to contribute to the cooling of the refrigerant gas and to contribute to the pre-cooling of the natural gas and its liquefaction.

[0075] The fraction of the main stream of natural gas F-P subjected to this second semi-open cycle is extracted from the main cryogenic heat exchanger at a temperature T4 (typically between -10°C and -40°C) above the temperature T3 to be directed towards the expansion turbine at intermediate temperature 8a in order to lower its temperature by expansion to a

temperature T5 (typically between -80°C and -110°C) lower than the temperature T4 and form a third stream of natural gas F-3.

[0076] The third stream of natural gas F-3 which may optionally contain a variable fraction of condensed liquid is then reintroduced into the main cryogenic heat exchanger to cool by heat exchange the initial stream of refrigerant gas G-0 and the main stream of natural gas F-P passing through the main cryogenic heat exchanger against the current.

[0077] At the outlet of the main cryogenic heat exchanger, the third stream of natural gas F-3 in gas phase and at a temperature T6 close to the temperature of the hot source is directed to a compressor 8b driven by the expansion turbine at intermediate temperature 8a to be compressed therein. It is then cooled by a natural gas cooler 26 before being mixed with the first stream of natural gas F-1 upstream of the natural gas compressor 12.

[0078] During its passage through the main cryogenic heat exchanger, the main stream of natural gas F-P is cooled by heat exchange with the first stream of natural gas F-1, the third stream of natural gas F3, and by a first stream of refrigerant gas G-1 (described later) all three streaming counter-currently through the main cryogenic heat exchanger 4.

[0079] At the outlet of the main cryogenic heat exchanger, the main stream of natural gas F-P has thus been cooled to a temperature allowing its liquefaction. This undergoes a Joule-Thomson expansion by passing through a valve 28 until it reaches a pressure close to atmospheric pressure. Alternatively, this expansion could be carried out by means of a liquid expansion turbine to improve its efficiency.

[0080] The expansion of the liquefied natural gas has the effect of generating flash gases which are separated from the liquefied natural gas in the balloon 18 dedicated for this purpose. At the outlet of the balloon, the stream of liquefied natural gas LNG freed from flash gases is sent to the LNG storage tanks.

[0081] As for the FF flash gases, they are sent to the main cryogenic heat exchanger to be reheated to a temperature T11 typically between -50°C and -110°C, then to a flash gas

treatment unit, which reduces the refrigeration power requirements in the cold section of the main cryogenic heat exchanger.

[0082] We will now describe the single closed refrigerant cycle with refrigerant gas (here predominantly nitrogen) which aims to provide additional thermal power to the other two refrigerant cycles and to ensure the sub-cooling of the liquefied natural gas.

[0083] The refrigerant gas compressor 14 delivers an initial stream of refrigerant gas G-0 which, after cooling in a refrigerant gas cooler 32, is at a temperature T7 close to the temperature of the hot source.

[0084] This initial stream of refrigerant gas G-0 is mainly circulated in the main cryogenic heat exchanger 4 to be pre-cooled there by heating the first stream of natural gas F-1, a third stream of natural gas F-3 as well as the first stream of refrigerant gas G-1 mentioned later circulating in counter-current in the main cryogenic heat exchanger.

[0085] At the outlet of the main cryogenic heat exchanger, the initial stream of refrigerant gas G-0 is at a temperature T8 (for example between -80°C and -110°C) which is lower than the temperature T7. This stream is directed to the low temperature expansion turbine 10a to be further cooled there to a temperature T9 (for example between -140°C and -160°C) below the temperature T8 before being reintroduced into the main cryogenic heat exchanger to form a first stream of refrigerant gas G-1.

[0086] As described above, the circulation of this first stream of refrigerant gas G-1 in the main cryogenic heat exchanger makes it possible to ensure by heat exchange a cooling of the main stream of natural gas F-P and of the initial stream of refrigerant gas G-0 streaming counter-currently through the main cryogenic heat exchanger.

[0087] At the outlet of the main cryogenic heat exchanger 4, the first stream of refrigerant gas G-1 is at a temperature T10 greater than T9 and close to the temperature of the hot source. This stream is directed to the compressor 10b driven by the low-temperature expansion turbine 10a to be compressed there before being cooled by a refrigerant gas cooler 34 and then reinjected as suction from the refrigerant gas compressor 14.

[0088] It will be noted that in the refrigerant gas compressor 14, the first refrigerant gas stream G-1 can be compressed in two successive compression phases between which the refrigerant gas stream can be cooled by another refrigerant gas cooler 30.

[0089] In connection with FIGS. 2 to 5, different variants of the liquefaction process according to the invention will now be described, it being noted that each of these variants can be implemented separately or combined with the others depending on the application case.

[0090] FIG. 2 illustrates a variant of the liquefaction process according to the invention known as “serial recompression”.

[0091] This variant differs from the embodiment of FIG. 1 in that the current at the discharge of the compressor 8b driven by the expansion turbine at intermediate temperature 8a is directed towards the suction of the compressor 6b driven by the expansion turbine at ambient temperature 6a (instead of being directly admitted to the suction of the natural gas compressor 12 as described in the embodiment of FIG. 1). At the exhaust from the compressor 6b, this natural gas stream passes through natural gas cooler 21 and is then admitted to the suction of the natural gas compressor.

[0092] This variant thus makes it possible to achieve staged compression of the natural gas which is more efficient than that described in connection with FIG. 1.

[0093] FIG. 3 illustrates another variant of the liquefaction process according to the invention known as “complementary pre-cooling by an auxiliary refrigerant cycle”.

[0094] This variant differs from the embodiment of FIG. 1 in that, during the first semi-open refrigerant cycle with natural gas, the stream of natural gas feed to the inlet of the expansion turbine at ambient temperature 6a is further cooled in an auxiliary heat exchanger 36.

[0095] As shown in FIG. 3, an auxiliary refrigeration cycle 38 provides the refrigeration power necessary for the operation of the auxiliary heat exchanger 36. This cycle can be for example a cycle with Hydro-Fluoro-Carbon (HFC) or with carbon dioxide.

[0096] In this variant, the temperature in the main separator 16 is lowered, which makes it possible to obtain better recovery of the NGLs.

[0097] FIG. 4 illustrates another variant of the liquefaction process according to the invention known as “absorption of NGL by sub-cooled reflux”.

[0098] In this variant, during the second semi-open refrigerant cycle with natural gas, the third stream of natural gas F-3 at the exhaust of the intermediate expansion turbine 8a is directed to an auxiliary separator 40 at the outlet of which the stream of natural gas is reintroduced into the main cryogenic heat exchanger 4, the stream of natural gas liquids at the outlet of the auxiliary separator 40 being pumped in whole or in part to the main separator 16 to contribute to the absorption of liquids from the natural gas.

[0099] The contact between the natural gas to be treated and the sub-cooled reflux can for example be carried out against the current. For this purpose, the main separator can for example be equipped with a packing bed. With this variant, it is possible to treat light gases with a high content of aromatic compounds (for example benzene) or to extract the LPGs with a high recovery rate (for example to ensure industrial production of LPGs).

[0100] FIG. 5 illustrates another variant of the liquefaction process according to the invention known as “absorption of NGL by reflux of LNG”.

[0101] In this variant, during the first semi-open refrigerant cycle with natural gas, part F-I of the fraction of the main natural gas stream F-P which passes through the main cryogenic heat exchanger 4 in order to be cooled there, is extracted from said exchanger of main cryogenic heat at a temperature T11 to be directed to the main separator 16 so as to contribute to the absorption of liquids from the natural gas.

[0102] The temperature T11 for extracting the stream F-I is higher than the temperature T3. It is for example between -70°C and -110°C.

[0103] The contact between the natural gas to be treated and the LNG reflux can for example

be carried out against the current. For this purpose, the main separator can for example be equipped with a packing bed. With this variant, it is possible to treat light gases with a high content of aromatic compounds in aromatic compounds (for example benzene) or to extract in particular LPGs with a high recovery rate and ethane.

P a t e n t k r a v

1. Fremgangsmåde til kondensation af en naturgas, omfattende en blanding af carbonhydrider, deraf overvejende methan, hvor fremgangsmåden omfatter:
- 5 a) en første halvåben kølemiddelcyklus med naturgas, i hvilken der successivt: blandes en tilførselsstrøm af forbehandlet naturgas (F-0) ved et tryk P0 for at ekstrahere sure gasser, vand og kviksølv derfra, med en naturgasstrøm, der ekspanderes ved et tryk P1, og hvis temperatur sænkes til en temperatur T1 ved
- 10 hjælp af en rumtemperatur-ekspansionsturbin (6a) for at opnå en kondensation af mulige væsker fra naturgassen, der indeholdes i naturgassen, adskilles eventuelle væsker fra naturgassen, der er kondenseret, i en hovedseparator (16) fra tilførselsstrømmen af naturgas, hvor sidstnævnte derefter passerer gennem en primær kryogen varmeveksler (4) for at danne en første
- 15 strøm af naturgas (F-1), der ved varmeveksling på den ene side bidrager til forudgående afkøling af en hovedstrøm af naturgas (FP), der strømmer modstrøms gennem den primære kryogene varmeveksler, og på den anden side til afkøling af en indledende strøm af kølegas (G-0), der strømmer modstrøms i den primære kryogene varmeveksler,
- 20 ved udløbet af den primære kryogene varmeveksler, komprimeres den første strøm af naturgas (F-1), som har en temperatur T2, der er større end T1 og tæt på temperaturen i en varm kilde, ved et tryk P2 ved hjælp af en kompressor (6b), der drives af rumtemperatur-ekspansionsturbinen (6a), før den ledes videre til indsugningen af en naturgaskompressor (12) til yderligere komprimering deri ved et tryk P3, der er større end P2, og for at danne en anden strøm
- 25 af naturgas (F-2), delvist ekspanderes den anden strøm af naturgas (F-2) ved udstødningen fra naturgaskompressoren (12) og blandes med tilførselsstrømmen af naturgas (F-0) opstrøms for rumtemperatur-ekspansionsturbinen og danner delvist hovedstrømmen af naturgas (FP),
- 30

passerer en fraktion af denne hovedstrøm af naturgas (F-P) gennem den primære kryogene varmeveksler for at blive afkølet til en temperatur T3, der er lav nok til at tillade kondensation af naturgassen;

b) en anden halvåben kølemiddelcyklus med naturgas, i hvilken der successivt:

ekstraheres en anden fraktion af hovedstrømmen af naturgas (FP) fra den primære kryogene varmeveksler ved en temperatur T4, der er større end T3, for at blive ledet til en mellemliggende ekspansionsturbine (8a), så dens temperatur sænkes ved ekspansion til en temperatur T5, der er lavere end T4, og danner en tredje strøm af naturgas (F-3),

genindføres den tredje strøm af naturgas (F-3) i den primære kryogene varmeveksler for ved varmeveksling at afkøle hovedstrømmen af naturgas og den indledende strøm af kølegas, der cirkulerer modstrøms ind i den primære kryogene varmeveksler,

ved udløbet af den primære kryogene varmeveksler ledes den tredje strøm af naturgas (F-3), der har en temperatur T6 tæt på temperaturen på den varme kilde, til en kompressor (8b), der drives af den mellemliggende ekspansionsturbine (8a), for at komprimeres deri, og derefter afkøles den, inden den blandes med den første strøm af naturgas opstrøms for naturgaskompressoren (12);

c) en lukket kølemiddelcyklus med kølegas, i hvilken der successivt:

cirkuleres en indledende strøm af kølegas (G-0) med en temperatur T7, der er tæt på temperaturen af den varme kilde og tidligere komprimeret af en kølegaskompressor (14), i den primære kryogene varmeveksler (4) for at blive forudgående afkølet deri,

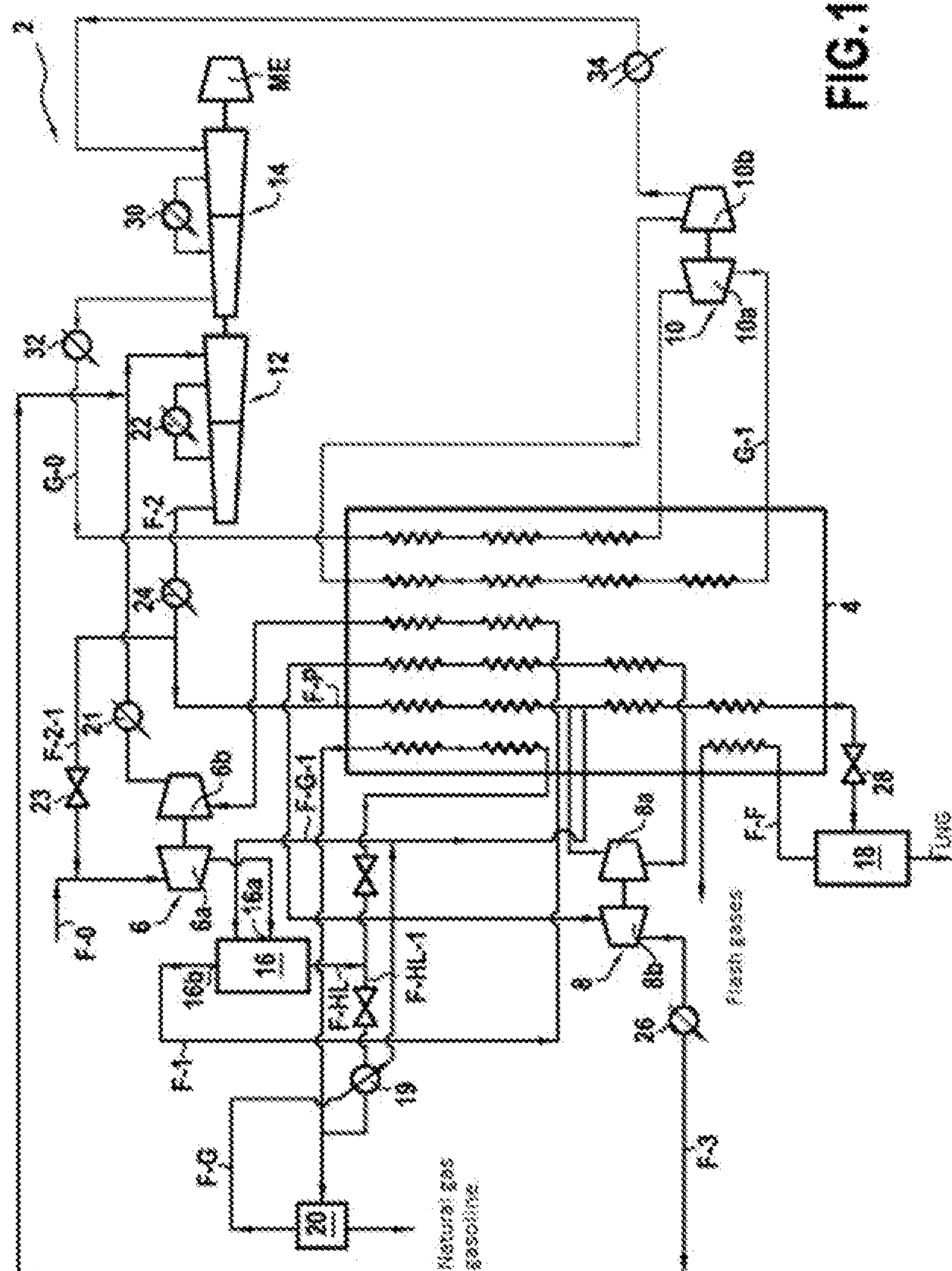
ved udløbet af den primære kryogene varmeveksler ledes den indledende strøm af kølegas (G-0), som har en temperatur T8, der er lavere end T7, til en lavtemperatur-ekspansionsturbine (10a), således at temperaturen sænkes ved ekspansion til en temperatur T9, der er lavere end T8, hvor den således dannede første strøm af kølegas (G-1) genindføres i den primære kryogene

- varmeveksler for at bidrage til afkølingen af hovedstrømmen af naturgas (FP) og den indledende strøm af kølegas (G-0);
ved udløbet af den primære kryogene varmeveksler ledes den første strøm af kølemiddelgas (G-1), som har en temperatur T10 tæt på temperaturen af den varme kilde, til en kompressor (10b), der drives af lavtemperatur-ekspansionsturbinen (10a), for at komprimeres deri, før den afkøles og derefter ledes til indsugningen af kølegaskompressoren (14).
- 5
2. Fremgangsmåde ifølge krav 1, hvor strømmen af naturgas ved udløbet af kompressoren (8b), der drives af den mellemliggende ekspansionsturbine (8a), under den anden halvåbne kølemiddelcyklus med naturgas afkøles og derefter blandes til den første strøm af naturgas, før den ledes til indløbet af kompressoren (6b), der drives af rumtemperatur-ekspansionsturbinen (6a).
- 10
3. Fremgangsmåde ifølge et af kravene 1 og 2, hvor tilførselsstrømmen af naturgas ved indløbet til rumtemperatur-ekspansionsturbinen (6a) afkøles yderligere i en hjælpevarmeveksler (36) under den første halvåbne kølemiddelcyklus med naturgas.
- 15
4. Fremgangsmåde ifølge et hvilket som helst af kravene 1 til 3, hvor den tredje strøm af naturgas (F-3) ved udstødningen af den mellemliggende ekspansionsturbine (8a) under den anden halvåbne kølemiddelcyklus med naturgas, ledes mod en hjælpeseparator (40), ved udløbet af hvilken strømmen af naturgas genindføres i den primære kryogene varmeveksler (4), hvor strømmen af væsker fra naturgassen ved udløbet af hjælpeseparatoren (40) pumpes i sin helhed eller delvis til hovedseparatoren (16) for at bidrage til absorptionen af væsker fra naturgassen.
- 20
- 25

5. Fremgangsmåde ifølge et hvilket som helst af kravene 1 til 4, hvor en del af fraktionen af hovedstrømmen af naturgas (FP), der passerer gennem den primære kryogene varmeveksler (4), under den første halvåbne kølemiddelcyklus med naturgas, for at blive afkølet deri, ekstraheres fra den primære kryogene varmeveksler ved en temperatur T11, der er højere end temperaturen T3, for at ledes til hovedseparatoren (16) for at bidrage til absorptionen af væsker fra naturgassen.
6. Fremgangsmåde ifølge et hvilket som helst af kravene 1 til 5, hvor tilførselsstrømmen af naturgas (F-0) ekspanderes under den første halvåbne kølemiddelcyklus med naturgas, og dens temperatur sænkes ved hjælp af rumtemperatur-ekspansionsturbinen (6a) uden forudgående afkøling i den primære kryogene varmeveksler.
7. Fremgangsmåde ifølge et hvilket som helst af kravene 1 til 6, hvor tilførselsstrømmen af naturgas ved udstødningen af rumtemperatur-ekspansionsturbinen (6a) under den første halvåbne kølemiddelcyklus med naturgas, indføres i hovedseparatoren (16), ved udløbet af hvilken en strøm af væsker fra naturgassen (F-HL) genvindes.
8. Fremgangsmåde ifølge krav 7, hvor den genvundne strøm af naturgasvæsker (F-HL) genopvarmes og fordampes delvist for at lette dens nedstrømsbehandling.
9. Fremgangsmåde ifølge et af kravene 7 og 8, hvor den termiske effekt, der er nødvendig for at genopvarme strømmen af naturgasvæsker (F-HL), kommer fra afkølingen af hovedstrømmen af naturgas (FP) og/eller den indledende strøm af kølegas (G-0).

- 10.** Fremgangsmåde ifølge et hvilket som helst af kravene 1 til 9, hvor trykket fra hovedstrømmen af naturgas (F-P) er større end det kritiske tryk af naturgassen.
- 5 **11.** Fremgangsmåde ifølge et hvilket som helst af kravene 1 til 10, hvor:
temperaturen T1 ligger mellem -40°C og -60°C;
temperaturen T3 ligger mellem -140°C og -160°C;
temperaturen T4 ligger mellem -10°C og -40°C;
temperaturen T5 ligger mellem -80°C og -110°C;
10 temperaturen T8 ligger mellem -80°C og -110°C;
temperaturen T9 ligger mellem -140°C og -160°C;
trykket P0 ligger mellem 5 og 10 MPa;
trykket P1 ligger mellem 1 og 3 MPa;
trykket P2 ligger mellem 2 og 4 MPa; og
15 trykket P3 ligger mellem 6 og 10 MPa.
- 12.** Fremgangsmåde ifølge et af kravene 1 til 11, hvor kølegassen hovedsageligt omfatter nitrogen.
- 20 **13.** Fremgangsmåde ifølge et hvilket som helst af kravene 1 til 12, hvor den er implementeret om bord på et off-shore-anlæg til kondensation af naturgas.
- 14.** Anlæg til kondensation af naturgas til udførelse af fremgangsmåden ifølge et hvilket som helst af de kravene 1 til 13, omfattende:
25 en rumtemperatur-ekspansionsturbine (6a) til modtagelse af en tilførselsstrøm af naturgas (F-0) såvel som en del af en anden strøm af naturgas (F-2) fra udløbet af en naturgaskompressor (12) og med en udstødning, der er forbundet med en indgang til en hovedseparator (16);
en primær kryogen varmeveksler (4) til modtagelse af naturgasstrømme (F-P,
30 F-1, F-3) og kølegas;

- en kompressor (6b), der drives af rumtemperatur-ekspansionsturbinen (6a) til modtagelse af en første strøm af naturgas (F-1) fra en hovedseparator (16) og med en udgang, der er forbundet til indsugningen af naturgaskompressoren (12);
- 5 en middeltemperatur-ekspansionsturbinen (8a) til modtagelse af en del af en hovedstrøm af naturgas (FP) fra udledningen af naturgaskompressoren (12) og forbundet ved indløbet og udløbet til den primære kryogene varmeveksler (4);
- 10 en kompressor (8b), der drives af middeltemperatur-ekspansionsturbinen (8a) til modtagelse af en tredje strøm af naturgas (F-3) fra den primære kryogene varmeveksler (4);
- en lavtemperatur-ekspansionsturbinen (10a) til kølegas, der er forbundet ved indløbet og udløbet til den primære kryogene varmeveksler (4); og
- 15 en kompressor (10b), der drives af lavtemperatur-ekspansionsturbinen (10a) og har et udløb, der er forbundet med indsugningen af en kølegaskompressor (14).
- 15.** Anlæg ifølge krav 14, hvor naturgaskompressoren (12) og kølegaskompressoren (14) drives af den samme drivmaskine (ME), der også tilvejebringer
- 20 den krævede effekt til trykforøgelsen af den naturgas, der skal kondenseres, samt til kompressionen af væsker, der cirkulerer i de tre kølemiddelcyklusser.
- 16.** Anlæg ifølge et af kravene 14 og 15, hvor naturgaskompressoren (12) er nedstrøms for kompressorerne, der drives af rumtemperatur-ekspansionsturbinen (6a) og mellemtemperatur-ekspansionsturbinen (8a), og hvor kølegaskompressoren (14) er nedstrøms for kompressoren, der drives af lavtemperatur-ekspansionsturbinen (10a).
- 25



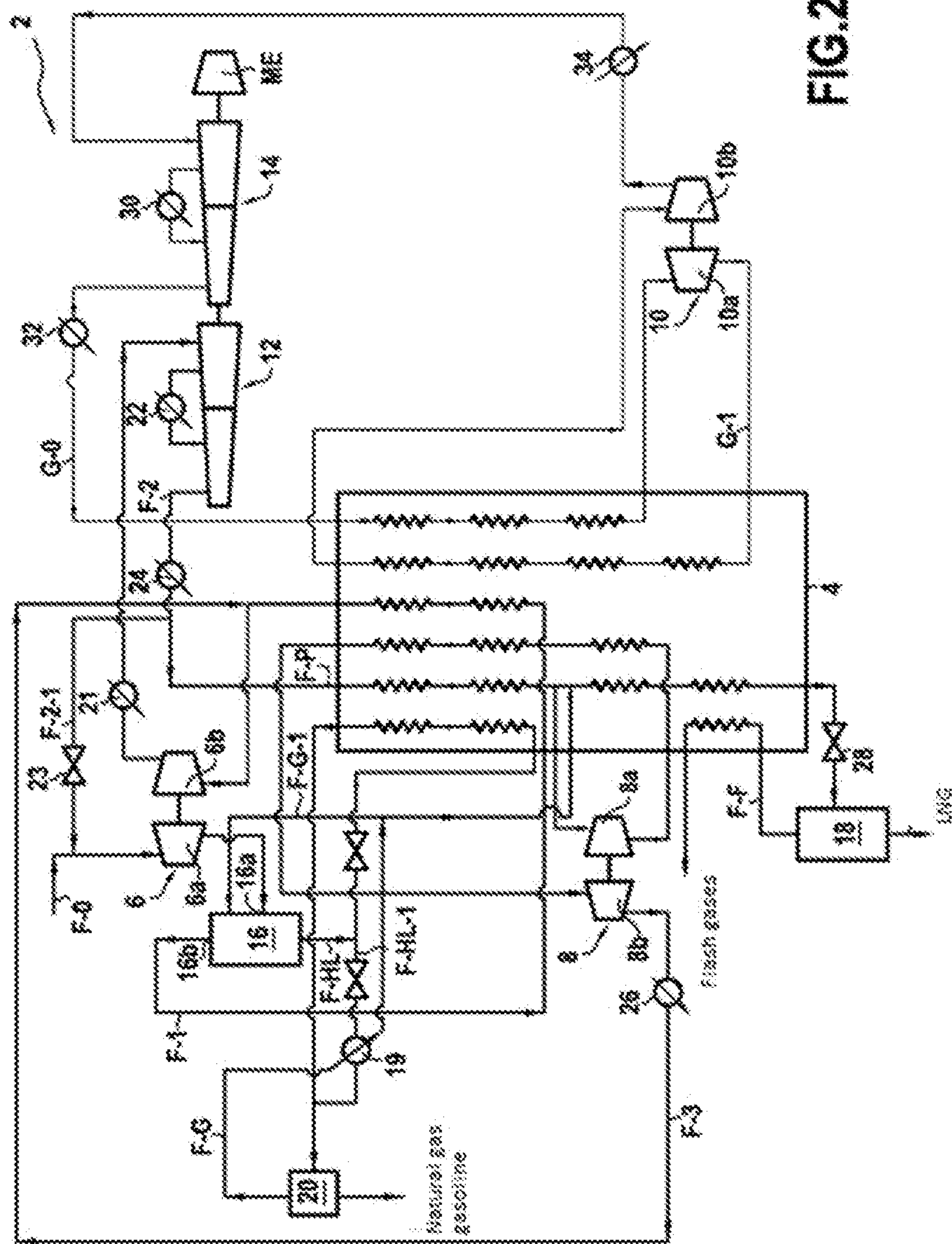


FIG. 2

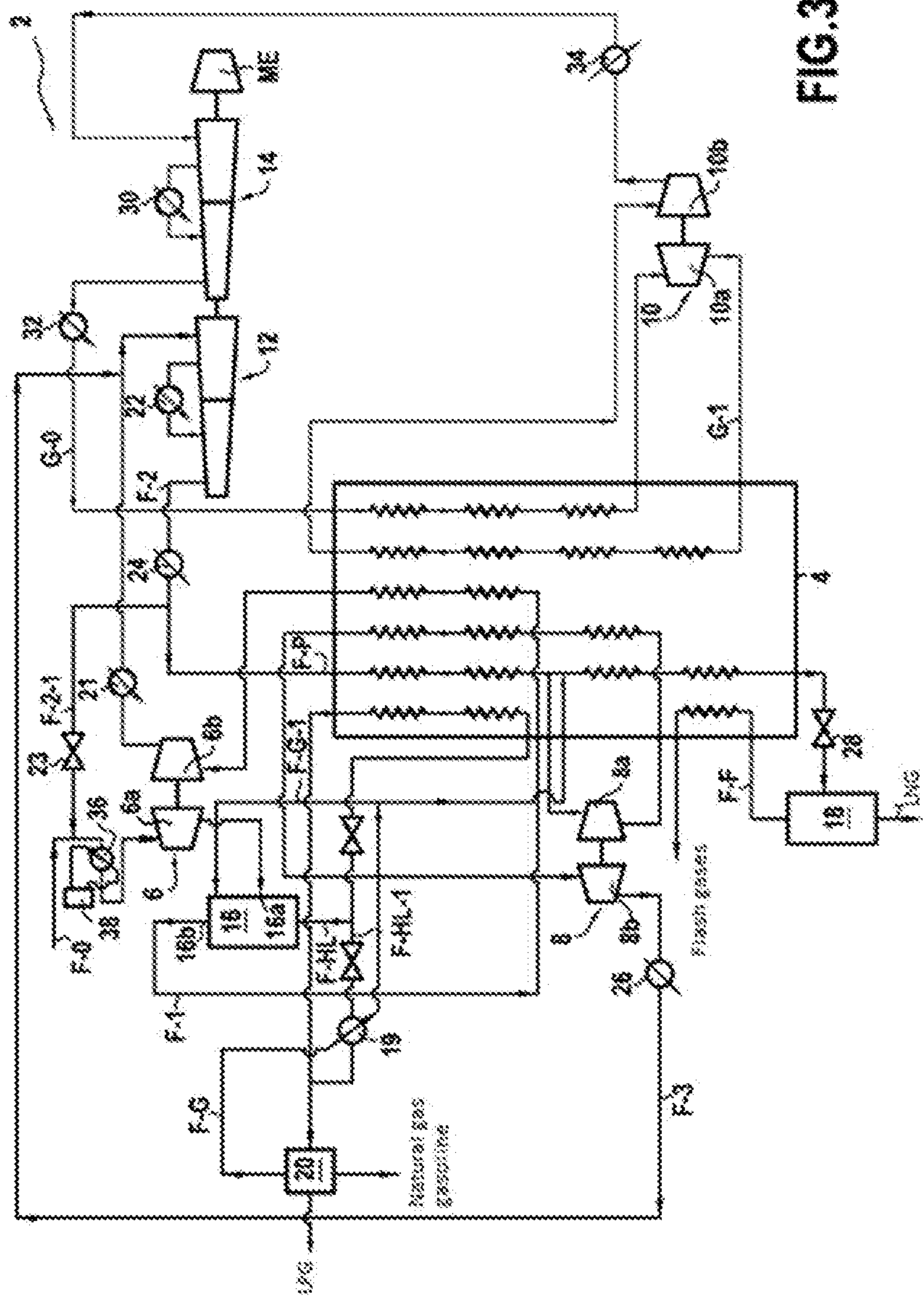


FIG. 3

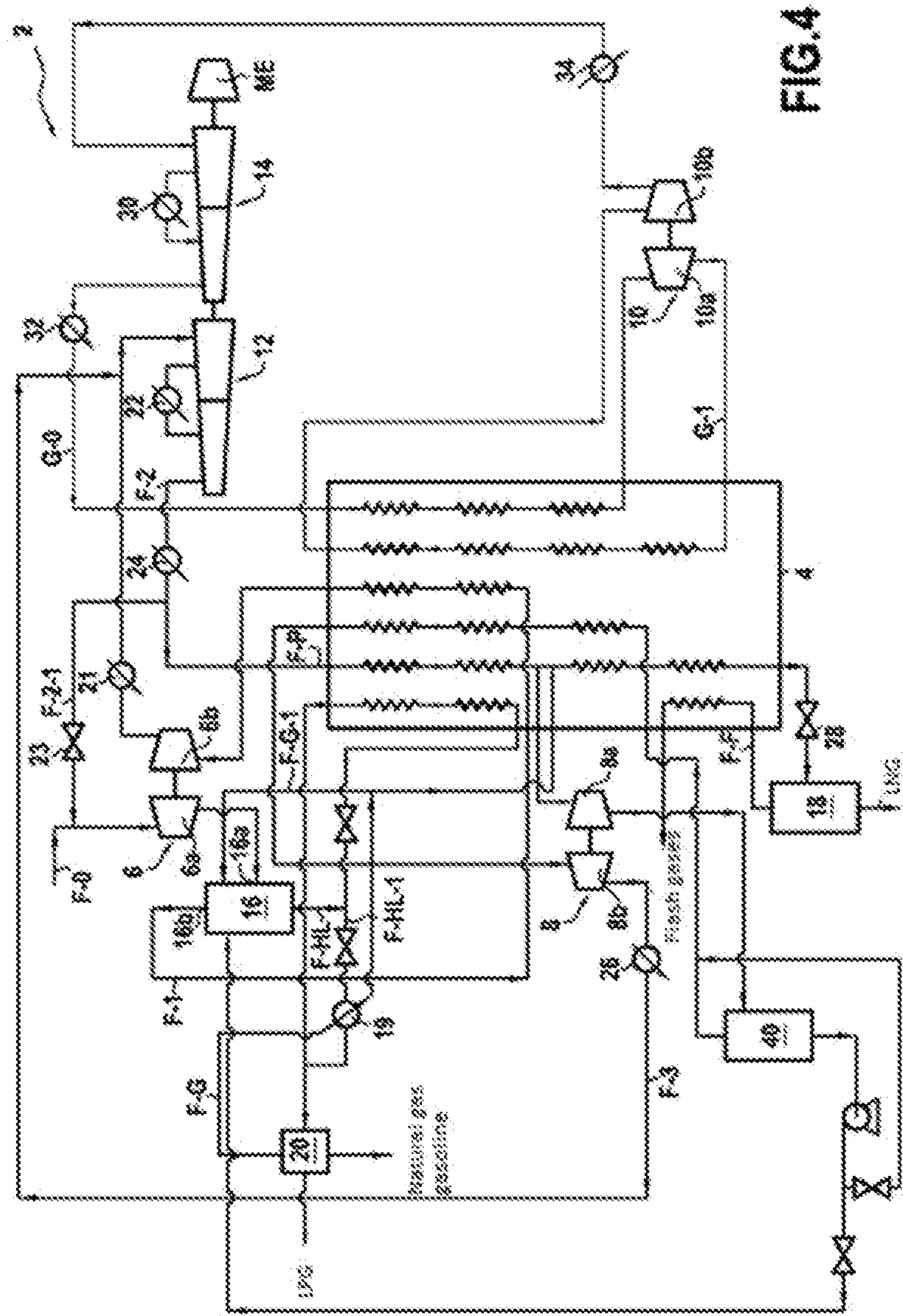
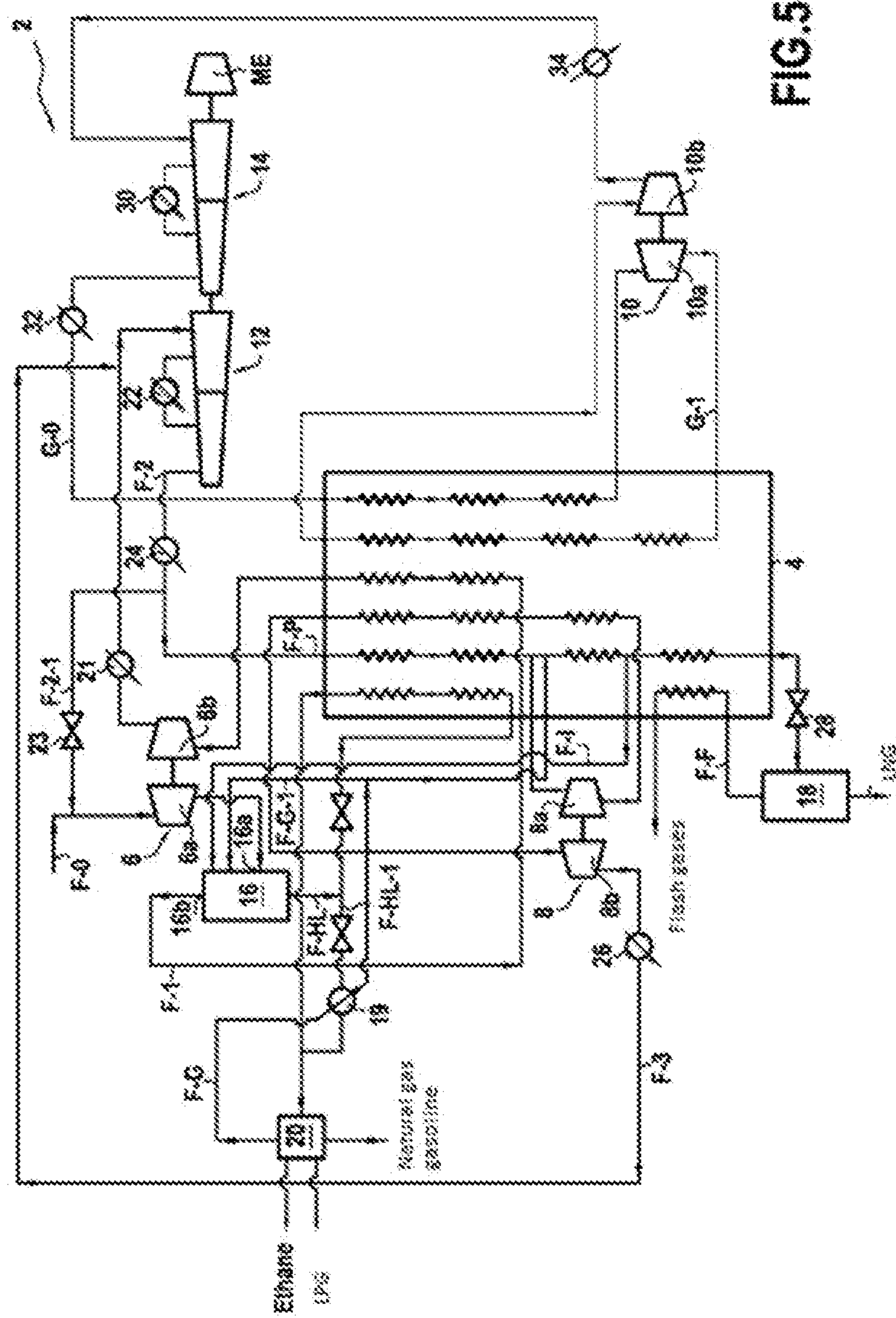


FIG. 4



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