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(73) Patenthaver: **Saipem S.p.A., Via Martiri di Cefalonia, 67, 20097 San Donato Milanese (Milano), Italien**

(72) Opfinder: **BONNISSEL, Marc, 3 rue de la Tarentaise, F-78180 Montigny Le Bretonneux, Frankrig**
DU PARC, Bertrand, 7 place des Quinconces, F-78960 Voisins Le Bretonneux, Frankrig
ZIELINSKI, Eric, 21bis rue du Maréchal Gallieni, F-78000 Versailles, Frankrig

(74) Fuldmægtig i Danmark: **Zacco Denmark A/S, Arne Jacobsens Allé 15, 2300 København S, Danmark**

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Description

Field of the invention

[0001] The present invention relates to a method for liquefying a natural gas to produce LNG, or Liquefied Natural Gas, also called LNG in English. More particularly still, the present invention relates to the liquefaction of natural gas comprising predominantly methane, preferably at least 85% methane, the other components essentially comprising nitrogen and C2-C4 alkanes, namely ethane, propane, butane.

[0002] The present invention also relates to a liquefaction installation arranged on a ship or a floating support at sea, either in the open sea or in a protected area, such as a port, or even an onshore installation in the case of small or medium-sized units for liquefaction of natural gas.

[0003] In the case of an installation placed on a ship, the present invention relates more particularly to a method for re-liquefying gas on board a LNG transport ship called a “methane tanker”, said gas to be re-liquefied being the result of reheating and partial evaporation of the LNG contained in the tanks of said vessel, said evaporated gas, in general mainly methane, being called in English “boil off”.

[0004] Methane-based natural gas is either a by-product of oil fields, produced in small or medium quantities, usually associated with crude oil, or a major product in the case of gas fields, where it is then in combination with other gases, mainly C-2 to C-4 alkanes, CO2, nitrogen.

[0005] When natural gas is combined in small quantities with crude oil, it is usually processed and separated, then used on-site as fuel in turbines or piston motors to produce electrical energy and heat used in process of separation or production.

[0006] When the quantities of natural gas are large or even considerable, it is sought to transport it so that it can be used in remote regions, generally on other continents, and to do this, the preferred method is to transport it to the cryogenic liquid state (-165°C) substantially at ambient atmospheric pressure. Specialized transport vessels called "methane tanker" have very large tanks with extreme insulation so as to limit evaporation during the voyage.

[0007] The liquefaction of gas for transport is generally carried out near the production site, generally on land, and requires considerable installations to reach capacities of several million tons per year, the largest existing units grouping together three or four liquefaction units of 3-4 Mt per year of unit capacity.

[0008] This liquefaction method requires considerable amounts of mechanical energy, the mechanical energy being generally produced on site by taking part of the gas to produce the energy necessary for the liquefaction method. Part of the gas is then used as fuel in gas turbines, steam turbines or reciprocating heat motors.

[0009] Multiple thermodynamic cycles have been developed in order to optimize the overall energy efficiency. There are two main types of cycles. A first type based on the compression and expansion of refrigerant fluid, with phase change, and a second type based on the compression and expansion of refrigerant gas without phase change. The term “refrigerant fluid” or “refrigerant gas” is used to refer to a gas or mixture of gases, circulating in a closed circuit and undergoing compression phases, where appropriate liquefaction, then heat exchanges with the external environment, then subsequently phases of expansion, where appropriate of evaporation, and finally of heat exchanges with the natural gas to be liquefied comprising methane, which gradually cools down to reach its liquefaction temperature at atmospheric pressure, i.e. approximately - 165°C in the case of LNG.

[0010] Said first type of cycle, with phase change, is generally used on land installations and requires a large amount of equipment and a considerable footprint. In addition, refrigerant fluids, generally in the form of mixtures, consist of butane, propane, ethane, and methane, these gases being dangerous because they risk, in the event of leakage, causing explosions or considerable fires. On the other hand, despite the complexity of the equipment required, they remain the most efficient and require an energy of around 0.3 kWh per kg of LNG produced.

[0011] Many variants of this first type of method with phase change of the refrigerant fluid have been developed and each supplier of technology or equipment has its own formulation of mixtures, associated with specific equipment, both for the so-called “cascade” methods, and for the so-called “mixed cycle” methods. The complexity of the installations comes from the fact that in the phases where the refrigerant is in the liquid state, and more particularly at the level

of the separators and the connecting pipes, it is necessary to install gravity collectors to bring together the liquid phase and direct it to the core of the heat exchangers where it will then vaporize on contact with the methane to be cooled and liquefied, to obtain LNG. These devices are very bulky, but this does not pose any problems in the case of land-based installations, because it is generally easy to have a sufficient land area to accommodate all these bulky equipment one beside the other. Thus, for onshore installations, all of the compression equipment, exchangers and collectors are generally installed side by side on considerable areas of 25 to 50,000m^2, or even more.

[0012] The second type of liquefaction method, a method without phase change of the refrigerant gas, is a reverse Brayton cycle, or Claude cycle using a gas such as nitrogen. The efficiency of this second type is lower, because it generally requires an energy of the order of 0.5 kWh/kg of LNG produced, i.e. about 20.84 kW x day/t and, on the other hand, it presents a considerable advantage in terms of safety, because the refrigerant gas of the cycle, nitrogen, is inert and therefore incombustible, which is very interesting when the installations are concentrated in a small space, for example on the deck of a floating support installed in the open sea, said equipment often being installed on several levels, one above the other on a surface reduced to the strict minimum. Thus, in the event of a refrigerant gas leak, there is no danger of explosion and it is then sufficient to reinject the lost refrigerant gas fraction into the circuit.

[0013] In addition, this method of liquefying natural gas without phase change is very advantageous in the case of floating supports, because, due to the absence of liquid phase in the refrigerant gas, the equipment is of much simpler design. In fact, in such installations, all of the equipment moves almost continuously to the rhythm of the movements of the floating support (roll, pitch, yaw, sheer, swing, heave). And the management of a method with phase change involving a liquid phase of the refrigerant would be extremely delicate even for weak movements of the floating support, or even almost impossible for extreme movements, whereas in fixed installations on land the problem of movements does not arise.

[0014] Despite the lower energy efficiency of the liquefaction method without phase change of the refrigerant gas, the latter remains very interesting because the equipment, mainly compressors, expanders, in turbines, and exchangers are much simpler than the equipment required for a liquefaction method involving phase change cycles of a refrigerant fluid, both in

terms of the technology of said equipment and of maintenance of this equipment in a confined environment, namely a floating support anchored at sea. In addition, the operation of the installations in operation remains simpler, since this type of cycle is not very sensitive to variations in the composition of the gas to be liquefied, namely a natural gas consisting of a mixture in which methane predominates. Indeed, in the case of the phase change cycle of the refrigerant fluid, for the yields to remain optimum, the refrigerant fluid must be adapted to the nature and composition of the gas to be liquefied and the composition of the refrigerant must be modified if necessary over time, depending on the composition of the mixture of natural gas to be liquefied produced by the oil field.

[0015] In principle, the implementation of a cycle of the liquefaction method without phase change of the refrigerant gas such as nitrogen comprises the following 4 main elements:

- a compressor which increases the pressure of the refrigerant gas and changes it from ambient temperature at low pressure to a high temperature at high pressure,
- a heat exchanger which cools the refrigerant gas from high temperature and high pressure substantially to ambient temperature and high pressure,
- an expansion device, in general a decompression turbine, in which the refrigerant gas expands: its pressure drops and its temperature is then very low; while, simultaneously, the mechanical energy is recovered at the level of the expansion turbine which is then generally directly reinjected at the level of the compressor which is coupled to it,
- a cryogenic exchanger in which circulates on one side the refrigerant gas at cryogenic temperature, and on the other the gas to be liquefied, said refrigerant gas absorbing the calories of the gas to be liquefied, therefore heating up, while said gas to be liquefied, yielding its calories, cools down to the desired liquid state. At the end of the circulation cycle, the refrigerant gas is approximately at ambient temperature and it is then reintroduced into the compressor to perform a new cycle in closed circuit.

[0016] Throughout the cycle, the refrigerant gas remains in the gaseous state and circulates continuously as explained previously: it gradually yields frigories, therefore gradually absorbs calories from the gas to be liquefied, namely a mixture consisting mainly of methane and other traces of gas.

[0017] The circulation of the gas to be liquefied takes place against the current of the refrigerant

gas, that is to say that said natural gas comprising methane enters substantially at room temperature into the exchanger at the level of the refrigerant gas outlet where the latter is then substantially at room temperature. Then, said natural gas comprising methane progresses through the exchanger towards the colder zones and transfers its calories to the refrigerant fluid: the natural gas comprising methane cools and the refrigerant gas heats up. As the natural gas methane progresses in the exchanger, its temperature drops, then at the end of its journey it liquefies and its temperature continues to drop until it reaches the temperature of T3 = -165°C for a gas containing 85% methane.

[0018] Throughout its journey in the heat exchanger(s), the liquefaction of natural gas takes place under pressure P0 of 5 to 50 bars, generally 10 to 20 bars, in four main phases:

- phase 1: cooling of natural gas from ambient temperature T0 to T1 = approximately -50°C (this temperature depends on the composition of the natural gas),
- phase 2: liquefaction of natural gas (transition from gaseous to liquid). As natural gas is a gaseous mixture under a pressure P0 of approximately a few tens of bars, this change of state ranges between T1 = -50°C and T2 = -120°C approximately,
- phase 3: once completely liquefied, the natural gas (LNG) is then at approximately T2 = -120°C, still under a pressure P0 of approximately a few tens of bars. Within the exchanger(s), the LNG continues to cool to reach the temperature T3 of - 165°C, a temperature corresponding to a liquid phase of the LNG under atmospheric pressure,
- phase 4: The liquid obtained or LNG is then depressurized to atmospheric pressure where it remains in the liquid state due to its temperature T3 less than or equal to -165°C, and can be transferred to an isolated storage tank, or where applicable loaded directly onto a transport vessel such as a methane tanker.

[0019] Phase 2 consumes the most energy, because the gas must be supplied with all the energy corresponding to its latent heat of vaporization. Phase 1 consumes a little less energy, and phase 3 consumes the least energy, on the other hand, it is done at the lowest temperatures, i.e. around -165°C.

[0020] The values mentioned above for T1, T2, and T3 are suitable for a natural gas consisting of 85% methane and 15% of said other nitrogen components and C-2 to C-4 alkanes, and can vary significantly for a gas of different composition.

[0021] In Figure 1, there is shown an installation diagram of a standard natural gas liquefaction method involving a refrigerant gas consisting of nitrogen without phase change of the refrigerant gas as described above and whose description of the method is explained later.

[0022] In US 2011/0113825 and WO 2005/071333, a natural gas liquefaction method is described in which said natural gas to be liquefied is liquefied by circulating said natural gas in 3 cryogenic heat exchangers by circulation in a closed circuit of 3 gas refrigerant streams remaining in the compressed gaseous state without phase change in which said natural gas to be liquefied is liquefied by carrying out the following concomitant steps of:

(a) circulation of said natural gas to be liquefied circulating at a pressure P0 greater than or equal to atmospheric pressure, in 3 cryogenic heat exchangers arranged in series, including:

- a first exchanger (101/5) in which said natural gas entering at a temperature T0 is cooled and exiting at a temperature T1 lower than T0, then
- a second exchanger (102/6) in which the natural gas is completely liquefied and leaves at a temperature T2 lower than T1 and higher than T3, T3 being lower than the liquefaction temperature of the LNG, and
- a third exchanger (103/7) in which said liquefied natural gas is cooled from T2 to T3, and

(b) closed-circuit circulation of two streams of refrigerant gas in the gaseous state called the first and third stream at different pressures P1 and P2, respectively, passing through two said exchangers in indirect contact with and against the flow of the natural gas stream, comprising:

- a first flow of refrigerant gas at a pressure P1 lower than P3 passing through the 3 exchangers entering said third exchanger at a temperature T3' lower than T3, then entering at T2' lower than T2 in said second exchanger, then entering at T1' lower at T1 in said first exchanger and leaving said first exchanger at a temperature T0' less than or equal to T0, said first flow of refrigerant gas at P1 and T3' being obtained by expansion in a first expander (112/9) of a first part (122/16B) of a second flow of refrigerant gas (22/15) compressed at a pressure P3 greater than P2, said first part of the second flow circulating in indirect contact with and co-current with said flow of natural gas, entering said first exchanger at T0 and leaving said second exchanger substantially at T2, and

- a third flow at a pressure P2 greater than P1 and less than P3 circulating in indirect contact with and co-current with said first flow, passing only through said second and first exchangers, entering said second exchanger at substantially a temperature T2' and exiting of said first exchanger substantially at T0', said third flow of refrigerant gas at P2 and T2 being obtained by expansion in a second expander (111/8) of a second part (121/17) of said second flow of refrigerant gas (22/15) leaving said first exchanger substantially at T1,

(c) said second flow of refrigerant gas compressed to pressure P3 being obtained by compression by three or four compressors, and cooling of said first and third flow of refrigerant gas leaving said first exchanger at P1 and P2, respectively.

[0023] In US 2011/0113825, two first and second compressors 113 and 114 arranged in series and compress the refrigerant gas from the first and third streams to P'3 and two other compressors 115a and 115b arranged in parallel compress from P'3 to P3.

[0024] In WO 2005/071333, two compressors 2 and 3 mounted in series compress said first stream 16d to P'_3 then a third compressor 4 mounted in series with the first two compressors compresses said first and third streams to P_3.

[0025] In the report of the « 24th International Conference and Exhibition for the LNG » of May 25, 2009, on behalf of Olve Skjeggedal et al. in the GASTECH 2009 review, a method as described above with triple flow of closed-circuit refrigerant gas is described, in which said first and third flows are compressed to P'3 by two compressors connected in series and two other compressors connected in series compress said first and third stream at P3 to give said second stream.

[0026] The method described above is advantageous compared to that of FIG. 1 in that, first of all, rather than recycling after expansion a part D2 of the second flow leaving the first exchanger to join the first flow at the inlet of the second exchanger, this part D2 of the second flow is recycled at the inlet of the second exchanger at an intermediate pressure P2 greater than P1 in a third independent flow S3 and parallel to S1, that is to say in co-current of S1. And, because most of the energy is consumed for phase 2 of the method within said second exchanger, this makes it possible to increase the heat transfers and the energy efficiency of the method.

[0027] However, in the embodiment of US 2011/0113825, all the external power supplied to said first compressor 113 and second compressor 114 mounted in series relates to the flow of refrigerant gas circulating at low and medium pressures P1 and P2, the energy recovery at the level of the turbines 111 and 112 being reinjected at the level of the two compressors 115a and 115b mounted in parallel compressing the high pressure refrigerant gas P'3 / P3, no other additional external power being supplied to said compressors in parallel 115a and 115b. The two compressors in parallel 115a and 115b are supplied only respectively by the two energy recovery turbines 111 and 112.

[0028] The pressure levels P1 and P2 of the gases leaving the turbines 112 and 111 are different and therefore, the flow rates passing through the expanders 111 and 112 are different and in particular in practice in a ratio of 10-20% of the total flow for the flow rate of the flow from the expander 112 against 80-90% for the flow rate from the expander 111. As a result, the compressor 115b recovers only 10-20% of the total power recovered compared to the 80-90% of power recovered at the compressor 115a. The result of this disparity in power supplied to the two compressors 115a and 115b mounted in parallel, is a major difficulty in stabilizing the operation of the circuit. Indeed, the operation of two compressors in parallel can lead to pumping phenomena, that is to say that one of the compressors takes precedence over the others by disturbing their inlet and outlet pressures: there is then a risk of the lower capacity compressor(s) operating in "turbine mode". This operating mode is to be absolutely avoided since all or part of the fluid then rotates in a loop between the compressors, one in compressor mode, the other or others in "turbine mode": the compression method is then radically disturbed, or even stopped and the overall efficiency of the installation then collapses.

[0029] The stabilization of the operation of the circuit can be carried out conventionally by means of control valves upstream and/or downstream of said compressors 115a and 115b mounted in parallel, and/or upstream and/or downstream of said turbines 111 and 112 to control the compressors flow rates and operation. However, these control valves generate pressure losses, and therefore energy, which greatly affects the desired overall efficiency and / or the production capacity of the installation.

[0030] In WO 2005/071333 and in the GASTECH 2009 review cited above, all the compressors are mechanically coupled to the same power source, all of the power being supplied in a non-

differentiated manner between the different compressors. US 2010/0122551 describes a method and an installation for triple flow liquefaction of refrigerant gas comprising compressors connected in series in accordance with the preambles of claims 1 and 14, respectively.

[0031] The aim of the present invention is to provide a method for the liquefaction of natural gas of the type without phase change of the refrigerant gas suitable for being installed on a vessel or floating support which has improved energy efficiency, namely a minimum total energy consumed in the method in terms of kWh to obtain 1 ton of LNG and/or which exhibits increased heat transfers in the exchangers and/or which makes it possible to implement a more compact and more efficient liquefaction installation.

[0032] To do this, the present invention provides a method for liquefying a natural gas comprising predominantly methane, preferably at least 85% methane, the other components essentially comprising nitrogen and C2-C4 alkanes, wherein said natural gas to be liquefied is liquefied by circulating said natural gas at a pressure P0 greater than or equal to atmospheric pressure (Patm), preferably P0 being greater than atmospheric pressure, in at least 1 cryogenic heat exchanger (EC1, EC2, EC3) by counter-current closed circuit circulation in indirect contact with at least one coolant gas flow remaining in gaseous state compressed at a pressure P1 entering said cryogenic exchanger at a temperature T3' lower than T3, T3 being the liquefaction temperature of said liquefied natural gas at the outlet of said cryogenic exchanger, T3 being lower than or equal to the liquefaction temperature of said natural gas liquefied at atmospheric pressure, wherein said natural gas to be liquefied is liquefied by carrying out the following concomitant steps of:

(a) circulating said natural gas to be liquefied circulating at a pressure P0 greater than or equal to atmospheric pressure, preferably P0 being greater than atmospheric pressure, in at least 3 cryogenic heat exchangers arranged in series including:

- a first exchanger wherein said natural gas entering at a temperature T0 is cooled and exits at a temperature T1 lower than T0, then
- a second exchanger wherein the natural gas is fully liquefied and exits at a temperature T2 lower than T1 and greater than T3, and
- a third exchanger wherein said natural gas liquefied is cooled from T2 to T3, and

(b) circulating in a closed circuit at least two flows of coolant gas in gaseous state named first and third flow at different pressures P1 and P2, respectively, passing through at least

said two exchangers in indirect contact with and against the natural gas flow (Sg), comprising:

- a first flow of coolant gas at a pressure P1 lower than P3 passing through the 3 exchangers entering said third exchanger at a temperature T3' lower than T3, then entering at a temperature T2' lower than T2 said second exchanger, then entering at a temperature T1' lower than T1 said first exchanger and exiting said first exchanger at a temperature T0' lower than or equal to T0, said first flow of coolant gas at P1 and T3' being obtained by expansion in at least a first expander of a first part of a second flow of coolant gas compressed at the pressure P3 greater than P2, said second flow circulating in indirect contact with and co-current of said natural gas flow by entering said first exchanger at T0 and said first part of the second flow exiting said second exchanger substantially at T2, and
- a third flow at a pressure P2 greater than P1 and lower than P3 circulating in indirect contact with and co-current of said first flow, passing only through said second and first exchangers, entering said second exchanger substantially at a temperature T2' and exiting said first exchanger substantially at T0', said third flow of coolant gas at P2 and T2 being obtained by expansion in a second expander of a second part of said second flow of coolant gas exiting said first exchanger substantially at T1, the flow rate D2 of said second part of second flow being preferably greater than the flow rate D1 of the first part of second flow,

(c) said second flow of coolant gas compressed at the pressure P3 being obtained by compressing by at least two compressors and cooling said first and third flows of coolant gas exiting said first exchanger at P1 and P2, respectively, a first compressor compressing from P1 to P2 all of said first coolant gas flow exiting said first exchanger, and at least a second compressor, compressing from P2 to at least P'3, P'3 being a pressure lower than or equal to P3 and greater than P2, on one hand said third flow of coolant gas exiting said first exchanger at P2, and on the other hand said first flow of coolant gas compressed at P2 exiting said first compressor, in order to obtain said second flow of coolant gas at P3 and T0 after cooling, said second compressor being mounted in series with said first compressor, characterized in that:

- both first and second compressors arranged in series are respectively coupled with said first and second expanders, consisting in energy recovery turbines, and

- at least said first compressor is coupled with a first motor, and allows to modulate and control specifically the value of the pressure P2 by providing a differentiated power to said first compressor compared to the power supplied to the other compressors, and
- at least one gas turbine is coupled
  - with either said second compressor, this one compressing said second coolant gas flow directly at P3,
  - or a third compressor connected in series after the second compressor, said third compressor compressing from P'3 to P3 said second coolant gas flow,
  - said first motor providing at least 3% of the total power supplied to all of said compressors implemented, said gas turbine providing 97 to 70% of the total power supplied to all of said compressors implemented.

[0033] In the present description, the term “compressor coupled to an expander/turbine or motor” or “compressor actuated by a motor” (or vice versa an “expander/turbine or motor coupled to the compressor”) is understood as the output shaft of the turbine or of the motor, respectively, drives the input shaft of the compressor, that is to say, transfers mechanical energy to the shaft of the compressor. It is therefore a mechanical coupling of the compressor to the expander/ turbine or respectively of the compressor to the motor.

[0034] More particularly, said motor can be either a heat motor, or preferably an electric motor, or any other installation capable of supplying mechanical energy to the refrigerant gas; and the compressors are of the rotary turbine type, also called a centrifugal compressor.

[0035] Preferably, after step (a), the liquefied natural gas leaving said third exchanger is depressurized at T3, from pressure P0 to atmospheric pressure where appropriate.

[0036] The method according to the invention is advantageous over the method described in US 2011/0113825 in that all the compressors are connected in series without requiring flow control with flow control valves to stabilize the operation of the installation. In fact, in the method according to the invention, there is no separation of flows in the compression chain. It follows that the regulation of flow rate of flow and/or energy at the level of the various compressors is obtained essentially by the regulation of the power input at the level of said first and second

motors and said gas turbine. It is not essential to implement control valves at said compressors and said turbine because said first and second expanders are coupled to said first and second compressors mounted in series and are therefore not coupled to compressors mounted in parallel as in US 2011/0113825.

[0037] On the other hand, in the present invention, most of the power supplied to said compressors is injected at the level of the second and/or third compressors compressing the flow of refrigerant gas at high pressure P'3/P3 and the recovery of energy at the level of the first and second expanders is reinjected at the level of the first and second compressors, compressing the refrigerant gases circulating at low and medium pressure P1 and P2. In fact, the fraction of fluid passing through compressor C1 represents a small fraction of the total flow (for example 10-15%) and the energy required is of the same order of magnitude as the energy recovered by turbine E1. It is therefore interesting to combine the two. In addition, a controlled addition of power in C1 makes it possible to improve the energy efficiency of the system by controlling P1 and P2 independently of one another.

[0038] On the other hand, most of the power supplied to the compressors is injected into the compressors providing the greatest pressure (P'3, P3), which makes it possible to increase the production capacity of the method, while improving its energy efficiency.

[0039] In addition, the implementation of said first and second compressors coupled in series with said first and second expanders according to the present invention also makes it possible to improve the compactness of the installation, which is particularly advantageous for the implementation of a method aboard a floating support where space is limited.

[0040] The method according to the invention with reference to FIGS 2 - 3 is advantageous over that of FIG. 1 in that, first of all, rather than recycling after expansion a part D2 of the second flow leaving the first exchanger to join the first flow at the inlet of the second exchanger, this part D2 of the second flow is recycled at the inlet of the second exchanger at an intermediate pressure P2 greater than P1 in a third independent flow S3 and parallel to S1, that is to say in co-current of S1. And, because most of the energy is consumed for phase 2 of the method within said second exchanger, this makes it possible to increase the heat transfers and the energy efficiency of the method.

[0041] On the other hand, the method according to the invention is advantageous compared to WO 2005/071333 and the method described in the GASTECH 2009 review cited above in that it allows said pressure P2 to be varied in a controlled manner so that the energy consumed for the implementation of the method (Ef) is minimal. Indeed, according to the present invention, it is possible to modulate and control specifically the value of the pressure P2 by providing a differentiated power at the level of said first compressor thanks to said first motor, making it possible to modulate and control the power supplied to the various compressors in a differentiated manner and therefore to vary the value of P2.

[0042] Thus, according to an original characteristic of the present invention, said pressure P2 is varied in a controlled manner by supplying power in a controlled manner to said first compressor with said first motor, in such a way that the energy consumed in carrying out the method (Ef) is minimal, preferably when the composition of the natural gas to be liquefied varies.

[0043] This method is more particularly advantageous because it thus makes it possible, by modulating and specifically controlling the value of the pressure P2 of said third flow, to modify and optimize the operating point of the method, namely to minimize the energy consumed and therefore to increase the efficiency, in particular when, as happens during operation, the composition of the natural gas to be liquefied varies.

[0044] According to the invention, said first motor provides at least 3%, preferably from 3 to 30%, of the total power supplied to all of said compressors implemented, said gas turbine providing 97 to 70% of the total power supplied.

[0045] More particularly still, it is observed that when the power injected into said first motor is increased, the pressure P1 remains substantially constant, the pressure P2 increases and the efficiency increases, that is to say that the energy consumption expressed in kW x day/t decreases, until it reaches a minimum, then by further increasing the power supplied by said motor, in particular beyond 30% of the total power, said energy consumption increases again.

[0046] A conventional liquefaction unit is dimensioned in relation to the powers of the gas turbines available, high power turbines commonly being 25MW, or even 30MW when they are

intended to be installed on a floating support. Fixed gas turbines installed on land can reach maximum powers of 90-100MW.

[0047] One generally seeks to increase the power of the installation, and it is then possible to install two identical gas turbines in parallel to obtain double power, but we then have two lines of rotating machines, which increases the dimensions, quantities of pipes and of course the costs.

[0048] By installing a single GT turbine of n MW and adding power of less than n MW at a said second motor M2, the operation of the method is identical in terms of efficiency to that using two gas turbines of n MW in parallel.

[0049] Thus, the addition of power at the level of the second motor M2, preferably by virtue of an electric motor, gives more flexibility in operation and thus allows an increase in power. On the other hand, the yield of the whole remains unchanged.

[0050] If, on the other hand, the same power is supplied to the first motor M1, the overall power is always the same, but in this case the efficiency of the assembly is improved, which represents a gain in energy consumed for the same overall power, compared to a power injection at the second motor M2.

[0051] Thus, depending on the production of natural gas, both in quantity and quality, from groundwater, a GT gas turbine, for example of 25MW, will advantageously be used, at full speed continuously that will be completed, or even if necessary modulate, by:

- power injection at the level of the GT turbine or of the second M2 motor without changing the overall efficiency, and/or
- power injection at the first motor M1, which has the effect of improving the overall efficiency, until an optimum is reached, i.e. a minimum of energy consumption.

[0052] In a first variant embodiment of the method, two compressors connected in series are used, comprising:

(i) said first compressor coupled with said first expander, compressing from P1 to P2 all of said first coolant gas flow exiting said first exchanger, and

(ii) said second compressor coupled with said second expander, compressing from P2 to at least P3, P'3 being greater than P2 and lower than or equal to P3, on one hand said third flow of coolant gas exiting said first exchanger at P2, and on the other hand said first flow of coolant gas compressed at P2 exiting said first compressor, in order to obtain said second flow of coolant gas at P3 and T0 after cooling, and

iii) said first compressor is driven by said first motor, said second compressor being driven by at least said gas turbine.

[0053] This first variant embodiment is advantageous in that it allows the most compact installation in terms of size on board the floating support.

[0054] In a second variant embodiment, three compressors connected in series are used, comprising:

(i) said first compressor driven by said first motor and coupled with said first expander, compressing from P1 to P2 all of said first coolant gas flow exiting said first exchanger, and

(ii) said second compressor driven by a second motor and coupled with said second expander, compressing from P2 to P'3, P'3 being greater than P2 and lower than P3, on one hand said third flow of coolant gas exiting said first exchanger at P2, and on the other hand said first flow of coolant gas compressed at P2 exiting said first compressor, and

(iii) said third compressor driven by said gas turbine to provide most of the energy and compress from P'3 to P3 all of the first and third coolant gas flows compressed by the second compressor, in order to obtain the second coolant gas flow at P3 and T0 after cooling, and

(iv) said first motor provides at least 3%, preferably from 3 to 30%, of the total power supplied to all of said compressors implemented, said gas turbine coupled with said third compressor, as well as said second motor coupled with the second compressor providing together from 97 to 70% of the total power supplied to all of said compressors implemented.

[0055] This second variant embodiment is advantageous in terms of thermodynamic efficiency and production capacity because a maximum capacity turbine available on the market can then be used advantageously, that is to say 25-30MW in the case of turbines intended to be installed

on a floating support, plus a second electric motor, for example from 5 to 10 MW connected to the second compressor, the overall power of the second motor and third motor (gas turbine) then being 30 to 40MW, therefore far superior to that of the largest gas turbines available on the market and intended for floating supports. Advantageously, the second motor can also be a gas turbine, preferably of identical power to the main gas turbine, which then makes it possible to achieve an overall power of 50 to 60 MW.

[0056] The method according to the invention makes it possible, by varying the pressure P2 by supplying energy to said first compressor using said first motor, to implement a minimum total energy Ef consumed in the method of less than 21.5 kW x day/t, more particularly from 18.5 to 20.5 kW x day/t of liquefied gas produced.

[0057] In general, one will operate with a gas turbine GT at full speed, which will be completed by a power supply to the first motor M1, said supply being limited to less than 30% of the overall power so to optimize the output to the minimum value of 18.5 to 21.5 kW x day/t, then if necessary, the overall power will be increased by power injection at the level of the second motor M2, and concomitantly the power injected at the level of the motor will be readjusted first motor M1, so that said power is always substantially equal to less than 30% of the overall power so as to keep the efficiency of the installation at the optimum value of 18.5 to 21.5 kW x day/t.

[0058] Said optimum efficiency of 19.75 kW x day/t for a power of the first motor M1 representing 24% of the total power is valid for a refrigerant fluid consisting of 100% nitrogen. In the case of other gases such as neon or hydrogen or nitrogen-neon or nitrogen-hydrogen mixtures, the optimum efficiency as well as the power percentage vary from 18.5 to 21.5 kW x day/t depending on the gas or the mixture and percentages of neon or hydrogen, but the advantages detailed above remain valid and even accumulate.

[0059] More particularly, said refrigerant gas comprises nitrogen.

[0060] In an alternative embodiment, said refrigerant gas consists of a single gas chosen from nitrogen, hydrogen, and neon.

[0061] Preferably, neon is preferred in view of the greater risk of explosion of hydrogen and the

fact that hydrogen may have a certain propensity to percolate through elastomeric seals and even through thin metal walls.

[0062] According to other particular characteristics:

- the composition of the natural gas to be liquefied is within the following ranges for a total of 100%:
- methane from 80 to 100%,
- nitrogen from 0 to 20%
- ethane from 0 to 20%
- propane from 0 to 20%, and
- butane from 0 to 20% ; et
- the following temperatures:
- T0 and T0' are from 10 to 35°C (temperature in AA), and
- T3 and T3' are from -160 to -170°C (temperature in DD), and
- T2 and T2' are from -100 to - 140°C (temperature in CC), and
- T1 and T1' are from -30 to -70°C (temperature in CC);

[0063] For the following pressures:

- P0 is from 0.5 to 5 MPa (5 to 50 bars), and
- P1 is from 0.5 to 5 MPa, et
- P2 is from 1 to 10 MPa (10 to 100bars), and
- P3 is from 5 to 20 MPa (50 to 200bars).

[0064] The present invention also provides an installation on board a ship or floating support for implementing a method according to the invention, characterized in that it comprises:

- at least said 3 cryogenic heat exchangers in series comprising at least:
- a first counter-current circulation conduit capable of circulating a first flow of coolant gas in gaseous state compressed at P1 passing in counter-current successively through the 3 third, second and first exchangers,
- a second co-current circulation conduit capable of circulating one said second flow of coolant gas in gaseous state compressed at P3 passing in co-current successively through only said first and second exchangers,

- a third counter-current circulation conduit of said coolant gas capable of circulating one said third flow of coolant gas in gaseous state compressed at P2 passing in counter-current successively through only said second and first exchangers ,
- a fourth conduit capable of circulating said natural gas to be liquefied passing successively through the 3 first, second, and third exchangers,
- a first expander between the outlet of the second conduit and the inlet of said first conduit,
- a second expander between (i) a bypass of said second conduit located between said first and second exchangers and (ii) the inlet of said third conduit, and
- a first compressor at the outlet of said first conduit, coupled with a turbine consisting said first expander,
- a second compressor at the outlet of said second conduit, coupled with a turbine consisting said second expander, and said second compressor being connected in series with said first compressor, and in particular at the outlet of said first compressor, and
- a conduit for circulating of all the compressed gas at P2 by the first compressor to the second compressor so connected in series with said first compressor, and
- at least a first motor coupled with said first compressor, capable of providing at least 3%, preferably from 3 to 30%, of the total power supplied to all of said compressors implemented, et
- a gas turbine coupled with either said second compressor, this one compressing said second coolant gas flow directly at P3, or to a third compressor connected in series after the second compressor, said third compressor compressing from P'3 to P3 said second coolant gas flow; and
- said gas turbine providing from 97 to 70% of the total power supplied to all of said compressors implemented.

[0065] More particularly still, a said installation only comprises two compressors connected in series, comprising:

(i) said first compressor coupled with said first expander, capable of compressing from P1 to P2 all of said first coolant gas flow exiting said first exchanger, and

(ii) said second compressor coupled with said second expander, capable of compressing from P2 to P3, on one hand said third flow of coolant gas exiting said first exchanger at P2, and on the other hand said first flow of coolant gas compressed at P2 exiting said

first compressor, in order to obtain said second flow of coolant gas at P3 and T0 after cooling, and

(iii) said first motor coupled with said first compressor, and said gas turbine coupled with said second compressor, said first motor being capable of providing at least 3%, preferably from 3 to 30%, of the total power supplied to all of said compressors implemented, et

(iv) said gas turbine coupled with said second compressor being capable of providing from 97 to 70% of the total power supplied.

[0066] More particularly still, an installation according to the invention comprises:

only three compressors connected in series, comprising:

(i) said first compressor coupled with said first expander and said first motor, and

(ii) said second compressor coupled with said second expander and a second motor, and

(iii) said third compressor coupled with said gas turbine capable of providing most of the energy and compress from at P3 all of the first and third coolant gas flows compressed by the second compressor, in order to obtain said third coolant gas flow at P3 and T0 after cooling, and

(iv) said first motor being capable of providing at least 3%, preferably from 3 to 30%, of the total power supplied to all of said compressors implemented, said gas turbine coupled with said third compressor, as well as said second motor coupled with the second compressor being capable of providing together from 97 to 70% of the total power supplied to all of said compressors implemented.

[0067] Other characteristics and advantages of the present invention will become apparent in the light of the detailed description of various embodiments which will follow, with reference to the following figures.

- FIG. 1 shows the diagram of a standard double loop liquefaction method using nitrogen as refrigerant gas,
- FIG. 2 represents the diagram of a liquefaction method according to the invention with a triple loop using nitrogen or a mixture comprising nitrogen as refrigerant gas, in a so-called “balanced” version,

- FIG. 3 represents the diagram of a liquefaction method according to the invention with a triple loop using nitrogen or a mixture comprising nitrogen as refrigerant gas, in a so-called “compact” version,
- FIG. 4 represents a diagram of cooling and liquefaction of a natural gas in the context of a liquefaction method according to the invention representing the enthalpy of natural gas and of the refrigerant fluid (kJ/kg) as a function of temperature from T0 to T3,
- FIGS. 5 and 5A represent diagrams of the total energy consumed (Ef) in kW x day per ton of LNG produced (kW x day/t) of a liquefaction method according to the invention using a mixture of nitrogen and neon as refrigerant gas, depending on the pressure P1 and the various neon percentages of said mixture,
- FIGS. 5 and 5B show diagrams the total energy consumed (Ef) kW x day/t of LNG produced from a liquefaction method according to the invention using a mixture of nitrogen and hydrogen as refrigerant gas, depending on the pressure P1 and the various percentages of hydrogen of said mixture,
- FIG. 6A represents a diagram of the total energy consumed (Ef) in kW x day/t of LNG produced from a liquefaction method according to the invention using a mixture of nitrogen and neon as refrigerant gas as a function of the pressure P2 and various neon percentages of said mixture,
- FIG. 6B represents diagrams of the total energy consumed (Ef) in kW x day/t of LNG produced from a liquefaction method according to the invention using a mixture of nitrogen and hydrogen as refrigerant gas, according to the pressure P2 and various percentages of hydrogen of said mixture,
- FIG. 7 shows a diagram of the total energy consumed (Ef) in kW x day/t of LNG produced from LNG produced in a prior art liquefaction method (60) and a liquefaction method according to the invention, using nitrogen as refrigerant gas according to the pressure level P3,
- FIG. 7A represents a diagram of the total energy consumed (Ef) in kW x day/t of LNG produced from a liquefaction method according to the invention using a mixture of nitrogen and neon as refrigerant gas as a function of the pressure P3 and various neon percentages of said mixture,
- FIG. 7B represents a diagram of the total energy consumed (Ef) in kW x day/t of LNG produced from a liquefaction method according to the invention using a mixture of nitrogen and hydrogen as refrigerant gas as a function of the pressure P3 and various percentages of hydrogen of said mixture.

[0068] FIG. 1 shows the PFD *(method Flow Diagram),* that is to say the flow diagram of the standard double loop method without phase change using nitrogen as refrigerant gas. The method comprises compressors C1, C2, and C3, expanders E1 and E2, intercoolers H1 and H2 as well as cryogenic exchangers EC1, EC2, and EC3. The heat exchangers consist, in a known manner, of at least two juxtaposed fluid circuits but not communicating with each other at the level of said fluids, the fluids circulating in said circuits exchanging heat all along the path within said thermal exchanger. Many types of thermal exchangers have been developed for the various industries and within the context of cryogenic exchangers two types predominate in a known manner: - on the one hand, wound exchangers, on the other hand so-called "brazed" aluminum plate exchangers, called in English "cold box".

[0069] Exchangers of this type are known to those skilled in the art and marketed by the companies LINDE (France) or FIVE Cryogénie (France). Thus, all the circuits of a cryogenic exchanger are in thermal contact with each other to exchange calories, but the fluids which circulate therein do not mix. Each of the circuits is dimensioned to present a minimum of pressure drops at the maximum flow rate of refrigerant fluid and sufficient resistance to withstand the pressure of said refrigerant fluid existing in the loop concerned.

[0070] Conventionally, an expander achieves a pressure drop of a fluid or a gas and is represented by a symmetrical trapezoid, the small base of which represents the inlet 10a (high pressure), and the large base represents the outlet 10b (low pressure) as illustrated in Figure 1 with reference to the expander E2, said expander can be a simple reduction in the diameter of the pipe, or an adjustable valve, but in the case of the liquefaction method according to the invention the expander is in general a turbine intended to recover mechanical energy during said expansion, so that this energy is not lost.

[0071] In the same way, and in a conventional manner, a compressor increases the pressure of a gas and is represented by a symmetrical trapezoid, the large base of which represents the inlet 11a (low pressure), and the small base represents the outlet 11b (high pressure) as illustrated in FIG. 1 with reference to compressor C2, said compressor generally being a turbine or a piston compressor, or even a scroll compressor. According to the invention, preferably (FIGS. 2 and 3), the compressors C1 and C2 are mechanically connected to a motor M1 and

M2 which can be either a heat motor or an electric motor, or any other installation capable of supplying mechanical energy.

[0072] The natural gas circulates in the circuit Sg and enters at AA in the first cryogenic exchanger EC1 at a temperature T0, greater than or substantially equal to the ambient temperature, and T1 = -50°C approximately. In this exchanger EC1, the natural gas cools, but remains in the gas state. Then it passes to BB in the cryogenic exchanger EC2, the temperature of which is between T1 = -50°C approximately and T2 = -120°C approximately.

[0073] In this exchanger EC2, all of the natural gas liquefies into LNG at a temperature of T2 = -120°C approximately, then the LNG passes to CC in the cryogenic exchanger EC3. In this EC3 exchanger, the LNG is cooled to a temperature of T3 = -165°C which allows the LNG to be discharged in the lower part in DD, then to depressurize it in EE to finally store it liquid at ambient atmospheric pressure, that is to say at an absolute pressure of approximately 1 bar (i.e. approximately 0.1 MPa). Throughout this natural gas journey in the Sg circuit in the various exchangers, the natural gas cools by releasing calories to the refrigerant gas, which then heats up and must permanently undergo a complete thermodynamic cycle in order to be able to extract in a manner continues natural gas calories entering AA.

[0074] Thus, the path of natural gas is shown on the left of the PFD, and said gas circulates from top to bottom in the circuit Sg, the temperature decreasing from top to bottom, from a substantially ambient temperature T0 at the top in AA, up to a temperature T3 of about -165°C at the bottom in DD.

[0075] On the right side of the PFD, there is shown the thermodynamic cycle of the double-loop refrigerant gas corresponding to circuits S1 and S2. For clarity of explanation, the pressure levels in the main circuits are shown in thin lines for low pressure (P1 in circuit S1), in medium lines for intermediate pressure (P2), and in solid lines for high pressure (P3 in circuit S2).

[0076] In a conventional diagram shown in FIG. 1, phases 1, 2, and 3 are carried out by a low pressure loop P1 at very low temperature at the lower inlet of EC3.

[0077] The installation is composed of:

- a motor, generally a gas turbine GT which drives the compressor C3 and provides all of the mechanical power,
- of 3 compressors:
    - C3 which compresses the entire flow of refrigerant,
    - C2 which is coupled to the turbine E2 and which compresses the portion D'2 of the total flow D, and
    - C1 which is coupled to the turbine E1 and which compresses the complementary portion D'1 of the total flow D,
- of 2 turbines,
    - E2 coupled directly to the compressor C2, and which expands the portion D2 of total flow D, from high pressure P3 to low pressure P1,
    - E1 coupled directly to the compressor C1, and which expands the portion D1 of total flow D, from high pressure P3 to low pressure P1,
- of a cryogenic exchanger in three parts or 3 exchangers in series EC1, EC2, and EC3, corresponding respectively to phase 1, phase 2, and phase 3 of liquefaction, comprising three circuits, SG (natural gas) and S1-S2 (gas refrigerant), respectively,
- of at least two coolers, H1 and H2, located at the outlet of the main compressor C3 (H1) and on the high pressure loop (H2), respectively, before entering the cryogenic exchangers.

[0078] A chiller H1, H2 can consist of a water exchanger, for example a sea or river water or cold air exchanger of the fan coil or cooling tower type, such as those used in nuclear power plants.

[0079] More specifically in FIG. 1, there is shown the diagram of a method and installation in which said natural gas to be liquefied is liquefied by carrying out the following concomitant steps of:

(a) circulating said natural gas to be liquefied circulating SG at a pressure P0 greater than or equal to atmospheric pressure (Patm), preferably P0 being greater than atmospheric pressure, in 3 cryogenic heat exchangers (EC1, EC2, EC3) arranged in series including:

- a first exchanger EC1 wherein said natural gas entering at a temperature T0 is cooled and exits BB at a temperature T1 lower than T0, at which all the components of said natural gas are still in the gaseous state, then

- a second exchanger EC2 wherein the natural gas is fully liquefied and exits at a temperature T2 lower than T1, and
- a third exchanger EC3 in which said liquefied natural gas is cooled from T2 to T3, T3 being less than T2 and T3 being less than or equal to the liquefaction temperature of said natural gas at atmospheric pressure, and

(b) circulation in a closed circuit against the current of a first flow S1 of refrigerant gas in the gaseous state compressed at a pressure P1 less than P3 in indirect contact with and against the current of the flow of natural gas Sg, said first flow S1 at a pressure P1 passing through the 3 exchangers EC3, EC2, and EC1 entering in DD into said third exchanger EC3 at a temperature T3' lower than T3 then leaving said third exchanger and entering said second exchanger EC2 in CC at a temperature T2' less than T2, then leaving the second exchanger and entering the first exchanger EC1 at BB at a temperature T1' lower than T1 and exiting at AA from said first exchanger EC1 at a temperature T0' less than or equal to T0,

- said first flow S1 of refrigerant gas at P1 and T3' being obtained by expansion in a first expander E1 of a first part D1 of a second flow S2 of refrigerant gas compressed at P3 greater than P1 circulating in co-current with said natural gas entering at AA in said first exchanger EC1 to T0 and leaving CC from said second exchanger EC2 substantially at T2, and
- a second part D2 of said second stream S2 of compressed refrigerant gas P3 circulating in co-current with said natural gas entering at AA in said first exchanger EC1 at T0 and leaving said first exchanger substantially at T1 is expanded in a second expander E2 at said pressure P1 and at a said temperature T2', and is recycled to join said first flow at the DC inlet of said second exchanger, and

(c) said second stream S2 compressed at P3 is obtained by compression by three compressors C1, C2, and C3 followed by at least two coolings H1 and H2 of said first stream S1 of recycled refrigerant gas leaving at AA from said first exchanger EC1, by a first compressor C1 coupled to said first expander E1, and

(d) after step (a), the liquefied natural gas is depressurized from pressure P0 to atmospheric pressure.

[0080] More precisely, in FIG. 1, 3 compressors are used, including 2 first and second compressors arranged in parallel comprising:

- a third compressor C3 actuated by a motor, preferably a gas turbine GT to compress from P**1** to P'3, P'3 being between P1 and P3, the whole of the first flow of refrigerant gas coming from the outlet at AA of said first EC1 exchanger, and
- a first compressor C1 coupled to the first expander E1 consisting of a turbine, for compressing from P2 to P'3, a part D1' of said first flow of refrigerant gas, compressed by the third compressor C3, and
- a second compressor C2 coupled to the second expander E2 consisting of a turbine, for compressing from P'3 to P3 a part D2' of said first flow of refrigerant gas compressed by the third compressor C3.

[0081] In FIG. 1, C1 and C2 are therefore arranged in parallel and operate between the medium pressure P'3 and the high pressure P3 over the entire flow from C3.

[0082] The refrigerant gas at the high outlet in AA of the circuit S1, at the level of the exchanger EC1 has a flow rate D: it is at low pressure P1 and at a temperature T'0 substantially lower than T0 and at ambient temperature. It is then compressed at C3 to the pressure P'3 then passes through a cooler H1. The flow rate fluid D is then separated into two parts of flow rates D1' and D2' which supply the compressors C1 (D1') and C2 (D2'), respectively, operating in parallel. The two flows at pressure P3 are then combined and then cooled substantially to ambient temperature T0 by passing through cooler H2. This overall flow D then enters the top of the cryogenic exchanger EC1 at the level of the circuit S2, then at the exit of the first level, in BB, a large part of the flow rate D2 (D2 greater than D1) is extracted and directed to the turbine E2 coupled to the compressor C2. The rest of the flow D1 passes through the second stage of the cryogenic exchanger EC2, then at level CC is directed towards the turbine E1 coupled to the compressor C1.

[0083] At the outlet of the turbine E1, the refrigerant gas, at a temperature T3' lower than T3 = -165°C, is then directed towards the bottom of the cryogenic exchanger EC3 in the circuit S1 and goes up against the current of the gas to be liquefied circulating in the circuit Sg, of which it ensures the final phase 3 of the liquefaction.

[0084] The flow D2 of refrigerant gas coming from the turbine E2 is at a pressure P1 and temperature T2 of about -120°C and is recombined within the circuit S1 to the flow D1 coming from the turbine E1 at the upper outlet of the cryogenic exchanger EC3 in CC.

[0085] The separation of the second flow S2 into two parts of different flow rates D1 and D2 at the outlet BB of the first exchanger, preferably with D2 greater than D1, is advantageous because most of the energy consumed occurs in phase 2 within the second exchanger EC2. Thus, only a minor part of the flow D1 passes through the third exchanger EC3 where phase 3 occurs, while the total flow D=D1+D2 of the circuit S1 then passes through the cryogenic exchanger EC2 to ensure phase 2 of the liquefaction (temperature from T1 = -50°C to T2 = -120°C).

[0086] The same flow D from circuit S1 finally passes through cryogenic exchanger EC1 to ensure phase 1 of the liquefaction method (temperature from T1 = -50°C to T0 = ambient temperature). At the upper outlet of the cryogenic exchanger EC1, the flow D of the circuit S1 is at the temperature T0′ substantially lower than the ambient temperature. Then, the flow D is again directed to the compressor C3 to continuously perform a new cycle.

[0087] In this configuration, the compressors C1 and C2 operate in parallel and must ensure the highest level of pressure in the cycle. The two compressors C1 and C2 process different refrigerant flow rates, D1'and D2', respectively, and are coupled directly to the turbines E1 and E2 which also process different flow rates, D1 and D2, respectively.

[0088] One has the relation:
D1 + D2 = D = D'1 + D'2, with D1 different from D'1 and D2 different from D'2. In practice, preferably D1/D = 5 to 35%, preferably 10 to 25%.

[0089] Thus, in this type of installation, all of the power is injected into the system at the level of compressor C3 (by the gas turbine GT), the power transfers at the level of the turbine compressor pairs E2-C2 and E1- C1 being variable as a function of the pressures in the various circuits (P1-P2-P3), the temperature levels at the inlet of the cryogenic exchangers, as well as the heat transfers within each of these said cryogenic exchangers.

[0090] Thus, such an installation has an operating point which stabilizes itself at a given energy level of consumption Ef generally expressed in kW x day/t, that is to say in kW-day per ton of LNG produced, or in kWh per kg of LNG produced, said operating point possibly being totally unstable. It is then very difficult to control the pressures of the high and low loops independently

of one another. This may prove to be necessary in the case of variations in the composition of the natural gas to be liquefied. It is possible to modify the flows by locally constraining all or part of the D1-D'1-D2-D'1 flows, for example by creating localized pressure drops, but such arrangements lead to energy losses, therefore a drop in the overall efficiency of the liquefaction installation.

[0091] The diagram in FIG. 4 illustrates the variation in enthalpy H, expressed in kJ / kg of LNG produced, in a natural gas liquefaction method. This diagram in figure 4 is the result of a theoretical calculation relating to a natural gas comprising mainly methane (85%), the remainder (15%) consisting of nitrogen, ethane (C-2), propane (C-3) and butane (C-4).

[0092] There is represented:

- phase 1 of natural gas cooling between points AA and BB corresponding to stage EC1 of the PFD in FIG. 1, corresponding to temperatures between ambient temperature T0 and T1 = -50°C,
- phase 2 of natural gas liquefaction between points BB and CC, corresponding to stage EC2 of the PFD in figure 1, corresponding to temperatures between T1 = -50°C and T2 = -120°C,
- phase 3 of LNG cooling between points CC and DD, corresponding to the EC3 stage of the PFD in FIG. 1, corresponding to temperatures between T2 = -120°C and T3 = -165°C.

[0093] The curve 50 comprises triangles to illustrate the variations in the enthalpy H of the fluids circulating in co-current in the circuits Sg and S2 as a function of the temperature of the gas to be liquefied comprising the methane/LNG for an ideal virtual process.

[0094] The curve 51 corresponds to the variation of the enthalpy H of the refrigerant gas circulating in the circuit S1 of FIG. 1, therefore represents the energy transferred to the circuits Sg and S2 during the liquefaction method.

[0095] The surface 52 between the two curves 50 and 51 represents the overall loss of energy consumed Ef in the liquefaction method: - it is therefore sought to minimize this surface so as to obtain the best efficiency. In land-based methods using refrigerant phase change methods, the curve 51 is no longer rectilinear, but is much closer to the theoretical curve 50, which implies

less losses, therefore improved efficiency, but the refrigerant phase change method is not suitable for liquefaction on board a floating support in a confined environment.

[0096] FIGS. 2 and 3 illustrate the PFD diagram of the improved method according to the invention, in which the path of the natural gas to be liquefied mainly comprising methane and traces of other gases, is identical to that of Figure 1, and performs in the same way within the circuit Sg, from the top (substantially ambient temperature T0) to the bottom (liquid state at T3 = -165°C), through three cryogenic exchangers EC1, EC2, and EC3.

[0097] In FIGS. 2 and 3, rather than recycling after expansion a part D2 of the second flow leaving the first exchanger to join the first flow at the lower inlet CC of the second exchanger, as in FIG. 1, this part D2 of the second flow is recycled at the inlet CC of the second exchanger at an intermediate pressure P2 greater than P1 in a third circuit S3 independent of S1, S2, SG, and parallel to S1, that is to say in co-current of S1.

[0098] Since most of the energy is consumed for phase 2 of the method within said second exchanger, this makes it possible to increase the heat transfers and the total energy efficiency of the method. But more importantly, it is also possible to specifically modulate and control the value of the pressure P2 by mounting the two compressors C1 and C2 in series and by coupling C1 with a motor M1 making it possible to modulate and control the additional power supplied to C1 already coupled to the turbine E1, and therefore to control the value of the pressure P2 as described below.

[0099] More precisely, in FIGS. 2 and 3, there is shown the method and installation in which said natural gas to be liquefied is liquefied by carrying out the following concomitant steps of:

(a) circulating said natural gas to be liquefied circulating Sg at a pressure P0 greater than or equal to atmospheric pressure (Patm), P0 being greater than atmospheric pressure, in 3 cryogenic heat exchangers EC1, EC2, and EC3 arranged in series including:

- a first exchanger EC1 wherein said natural gas entering at a temperature T0 is cooled and exits BB at a temperature T1 lower than T0, temperature T1 at which all the components of said natural gas are still in the gaseous state, then
- a second exchanger EC2 wherein the natural gas is fully liquefied and exits at a temperature T2 lower than T1, and

- a third exchanger EC3 in which said liquefied natural gas is cooled from T2 to T3, T3 being less than T2 and T3 being less than or equal to the liquefaction temperature of said natural gas at atmospheric pressure, and

(b) closed-circuit circulation of two streams S1 and S3 of refrigerant gas in the gaseous state called the first and third stream, respectively, at different pressures P1 (S1) and P2 (S2), passing through two said exchangers in indirect contact with and against the flow of the natural gas stream Sg, comprising:

- a first flow of coolant gas S1 at a pressure P1 lower than P3 passing through the 3 exchangers EC1, EC2, and EC3 entering at DD said third exchanger EC3 at a temperature T3' lower than T3, then leaving said third exchanger and entering said second exchanger EC2 at CC at a temperature T2' lower than T2, then leaving the second exchanger and entering the first exchanger EC1 at BB at a temperature T1' lower than T1 and leaving said first exchanger at a temperature T0' lower than T0 at AA, said first flow of refrigerant gas at P1 and T3 'being obtained by expansion in a first expander E1 of a part D1 of a second flow S2 of refrigerant gas compressed at the pressure P3 greater than P2, said second flow S2 circulating in contact indirect with and co-current of said natural gas flow Sg entering at AA in said first exchanger EC1 substantially at T0 and exiting at CC from said second exchanger EC) substantially at temperature T2, and
- a third flow S3 at a pressure P2 greater than P1 and less than P3 circulating in indirect contact with and co-current with said first flow, passing only through said second and first exchangers EC2 and EC1, entering at CC said second exchanger at substantially a temperature T2' lower than T2 and exiting at AA of said first exchanger EC substantially at a temperature T0', said third flow S3 of refrigerant gas at P2 and T2 being obtained by expansion in a second expander E2 of a part D2 of said second flow S2 of refrigerant gas leaving said first exchanger substantially at T1,

(c) said second flow of refrigerant gas S2 compressed to the pressure P3 being obtained by compressing said first and third flow of refrigerant gas leaving at AA from said first exchanger EC1 to P1 and P2, respectively, by two first and second compressors, C1 and C2, respectively, arranged in series and coupled to said first and second expanders E1 and E2, respectively, consisting of turbines, and

(d) after step (a), the liquefied natural gas leaving said third exchanger at DD is depressurized at T3, from he pressure P0 to atmospheric pressure where appropriate.

[0100] More specifically, in Figure 2, are implemented:

1. (1) three compressors C1, C2, and C3 mounted in series, comprising:

   (i) a first compressor C1 coupled with said first expander E1, compressing from P1 to P2 all of said first coolant gas flow exiting at AA of said first exchanger EC1, and

   (ii) a second compressor C2 coupled with said second expander E2, compressing from P2 to P'3, P'3 being greater than P2 and lower than or equal to P3, on one hand said third flow S3 of coolant gas exiting said first exchanger EC1 at P2, and on the other hand said first flow of coolant gas compressed at P2 exiting said first compressor C1, and

   (iii) a third compressor C3 driven by said gas turbine GT to provide most of the energy and compress from P'3 to P3 all of the first and third coolant gas flows compressed by the second compressor C2, in order to obtain the second coolant gas flow at P3 and T0 after cooling (H1, H2), and

(2) said first compressor C1 is coupled to a first motor M1, making it possible to vary the pressure P2 in a controlled manner by supplying power in a controlled manner to said first compressor C1, said first motor M1 providing at least 3%, preferably from 3 to 30%, of the total power supplied to all of said compressors implemented C1, C2, and C3, said gas turbine GT coupled with said third compressor C3, as well as said second motor M2 coupled with the second compressor C2 providing together from 97 to 70% of the total power supplied to all of said compressors implemented C1, C2, and C3.

[0101] The installation of FIG. 2 is thus composed of:

- a plurality of motors, in general a gas turbine GT which drives the compressor C3 and motors M1-M2, for example either electric or thermal, such as gas turbines, respectively connected to the compressors C1-C2,
- 3 compressors:
  - C3 which compresses the entire flow of refrigerant gas D,
  - C2 which is coupled to the motor M2 and to the turbine E2, and which compresses the entire flow of refrigerant gas D,
  - C1 which is coupled to the motor M1 and to the turbine E1, and which compresses the portion D1 of the first flow of refrigerant gas,
- 2 expander, for example turbines,

- E2 coupled to the compressor C2 and the motor M2,
- E1 coupled to the compressor C1 and the motor M1,
- of a cryogenic exchanger in three parts or 3 exchangers in series EC1, EC2, and EC3, corresponding respectively to phases 1, 2, and 3 of liquefaction, comprising four circuits, SG (natural gas) and S1-S2-S3 (gas refrigerant), respectively,
- of two coolers, H1 and H2, located at the outlet of the main compressor C3 (H2) before entering the circuit S2 of the cryogenic exchangers, and on the high pressure loop (H1).

[0102] The compressors C1 and C2 are mounted in series.

- C1 operates between low pressure P1 and medium pressure P2, on the portion D1 of the flow of refrigerant gas coming from the turbine E1 circulating in the circuit S1, from bottom to top, through each of the three cryogenic exchangers EC3-EC2-EC1.
- C2 operates between the medium pressure P2 and the intermediate high pressure P'3 on the entire flow D, composed of the portion D1 of the flow coming from the compressor C1 and the portion D2 of the refrigerant gas flow coming from the turbine E2 circulating in the circuit S3, from bottom to top, through each of the two cryogenic exchangers EC2-EC1.

[0103] The entire flow of refrigerant gas D leaving the compressor C2 is cooled in a cooler H1 before returning to pressure P'3 in the compressor C3, the latter being connected to a motor (GT), generally a gas turbine. Said gas turbine and the motor (M2) together supply the refrigerant gas from 70 to 97% of the overall power Q, the remainder of the power being supplied to the system at the level of the motor M1, namely from 30 to 3% of the overall power Q.

[0104] At the outlet of the compressor C3, the entire flow of refrigerant gas D is at the high pressure P3. The flow is then cooled in a cooler H2 before circulating in the circuit S2, from top to bottom, through each of the two cryogenic exchangers EC1-EC2.

[0105] The portion D2 of the refrigerant gas flow is taken at BB at the outlet of the cryogenic exchanger EC1 and directed towards the inlet of the turbine E2, the remainder, i.e. the portion D1 of the refrigerant gas flow being taken in DC at the outlet of the cryogenic exchanger EC2 and directed towards the inlet of the turbine E1.

[0106] Within the compressor C3, a cooler H2 operating at the pressure P'3 is installed between two compression stages, said cooler H2 treating the entire stream D.

[0107] In this process according to the invention, the relationships are:
D1 + D2 = D and preferably D1/D2=1/3 to 1/20, preferably from 1/4 to 1/10.

[0108] The main advantage of the device according to the invention of FIG. 2 lies in the possibility of optimizing the overall efficiency of the installations and of modifying at will the operating points of the various loops corresponding to the circuits S1-S2-S3, that is to say to minimize the energy consumed by increasing or reducing the power injected into one of the compressors C1-C2-C3, or by varying the distribution of the overall power Q injected into the system. These power adjustments injected into the various compressors C1-C2-C3 have the effect of modifying the flow rates in the various loops, therefore modifying the pressures P1, P2 & P3 as well as the mass flows D, D1 and D2 in the various S1-S2-S3 circuits, which gives great flexibility in optimizing the operating point of the installation and therefore great ease and great speed during process readjustments following fluctuations in the composition of the natural gas at liquefy from underground reservoirs. These variations can be significant during the life of the gas production field, which can extend over 20 to 30 years, or even more.

[0109] Thus, in the diagram of FIG. 4 relating to a natural gas comprising 85% of methane, the remainder consisting of nitrogen, ethane (C-2), propane (C-3) and butane (C- 4), the curve 50 comprising triangles, illustrates the variations of the enthalpy H of the fluids circulating in the circuits Sg and S2 of FIG. 2 as a function of the temperature of the natural gas / LNG for an ideal virtual process.

[0110] The curve 53 corresponds to the variation of the enthalpy H of the refrigerant fluid circulating in the circuits S1 and S3 of FIG. 2, therefore represents the energy transferred to the circuits Sg and S2 of FIG. 2 during the liquefaction method.

[0111] The surface 52 between the two curves 50 and 53 represents the overall energy loss in the liquefaction process with reference to FIG. 2: - it is therefore sought to minimize this surface so as to obtain the best efficiency.

[0112] During variations over time in the quality of the natural gas supplied by the gas field, and therefore in its composition, the low point 54 of the curve 50 corresponding to P0 and T2 at the end of LNG liquefaction, may vary by a few %. In the conventional process of FIG. 1, the corresponding point 55 of the refrigerant gas circuit remains substantially fixed, and the surface 52, therefore, the efficiency of the installation cannot be optimized.

[0113] On the other hand, in the device according to the invention according to FIG. 2, by playing on the distribution of the mechanical energy and in particular on the energy injected into GT, into M1 and M2, and more particularly into M1, it is possible to make advantageously vary the position of point 56, which is thus known to move optimally in the direction of point 54, which makes it possible to reduce to a minimum the surface area of area 52 between curves 50 and 53, and thereby optimizing the efficiency of the liquefaction plant in real time, depending on the composition of the natural gas.

[0114] FIG. 3 represents the PFD diagram of a version of the invention exhibiting an improved compactness compared to the method and installation of FIG. 2, in which the compressor C2 is integrated on the same shaft line as the compressor C3 and is actuated by the gas turbine GT representing a mechanical energy input of 85 to 95% of the total energy Q. In this configuration, the expansion turbine E2 is then connected on the one hand to the compressor C2 and to the other hand to the GT gas turbine.

[0115] In this version of FIG. 3 exhibiting greater compactness than the version described with reference to FIG. 2, however, there is less latitude to adjust the operating points of the various loops, because the power adjustments can then be made only at the level of GT motors connected to C3 and M1 connected to C1. Thus, this compact version is advantageously justified in the event of a very limited available surface area, and in addition there are only two rows of rotating machine shafts and two compressors, whereas in the version with reference to FIG. 2, we must install three lines of rotating machine shafts and three compressors, which represents a significant additional cost, but provides greater flexibility in the fine adjustment of the various pressure loops, as well as better final efficiency, therefore better profitability of long-term installation, throughout the lifetime of the installation which exceeds 20 to 30 years, or even more.

[0116] In FIGS. 5 to 9 discussed below, we reproduce the results of the tests in which the values of P1, P2, and P3 are varied to minimize the total energy consumed Ef in kW x day/t as a function of the variation of the composition of the refrigerant gas.

[0117] In FIGS. 5-5A-5B, there is shown the diagram of the energy yield, more precisely of Ef expressed in kW x day/t, as a function of the pressure P1, and as a function of the various variants of the invention. In fact, this pressure P1 is constant for a given refrigerant gas composition, which explains why all the points of the same curve are on a line parallel to the ordinates. This pressure P1 corresponds to the lowest temperature T3' of the device, that is to say to the temperature at the low inlet of the cryogenic exchanger EC3. This pressure P1 corresponds substantially to the dew point of the refrigerant gas at a temperature T3' substantially lower than T3=-165°C, that is to say the temperature at which the LNG will remain liquid under a pressure corresponding to atmospheric pressure, i.e. substantially 0.1MPa absolute, i.e. substantially one atmosphere.

[0118] In FIGS. 5, 5A and 5B, it is observed that by mixing nitrogen with neon or hydrogen, up to a molar proportion of 50%, the pressure P1 can be increased, which is accompanied by a reduction in the optimum energy consumed at the stabilized operating point, and therefore a better energy efficiency of the liquefaction process.

[0119] On the other hand, in diagram 5A relating to a nitrogen-neon mixture, the operating point in the case of the conventional process of FIG. 1 with pure nitrogen is located at 60. The curve 70 (left portion) represents the variation in energy efficiency as a function of the power injected into the process at the level of the motor M1 with reference to FIGS. 2 and 3. The upper point W0=0 of curve 70 corresponds to an unpowered motor M1, therefore providing zero power. The point W1 corresponds to a power W1>0 supplied by said motor M1. Likewise, the successive points of the curve correspond to increasing powers supplied to the system at the level of the motor M1, namely W4>W3>W2>W1>W0=0.

[0120] The points W0 to W4 correspond to powers injected into the motor M1:

W0 = zero power,

W1 = 7% of the overall power,

W2 = 15% of the overall power,

W3 = 24% of the overall power,
W4 = 33% of the overall power.

[0121] Similarly in the diagram of FIG. 6A, the energy efficiency is shown as a function of the pressure P2, and as a function of the various variants of the invention. The curve 90 represents the method according to FIG. 2 using a refrigerant gas composed of 100% nitrogen. As in FIG. 5A, the upper point W0=0 of the curve 90 corresponds to an unpowered motor, therefore providing zero power. The point W1 corresponds to a power W1>0 supplied by said motor M1. Likewise, the following points of the curve correspond to increasing powers supplied to the system at the level of the motor M1, namely W4>W3>W2>W1>W0=0: - said powers W1 to W4 being identical in FIGS. 5A and 6A.

[0122] Thus, in this same FIG. 6A, it is observed that when the power W injected at the level of M1 is increased, the pressure P1 remains constant, but the pressure P2 increases and the efficiency increases, that is to say that the consumption in energy expressed in kW x day/t decreases, until it reaches a minimum 90a, here substantially coincident with point W3, then said energy consumption increases again towards W4. This minimum 90a corresponds to the low point 70a of the curve 70 in FIG. 5A, for a minimum energy consumption of approximately 19.75 kW x day/t, a pressure P1 of approximately 9 bars and a pressure P2 of approximately 28 bars. In comparison, the operating point W0 without energy input to the motor M1 corresponds, for a pure nitrogen method, to an energy consumption of approximately 21.25 kWxd/t, at the same pressure P1 of approximately 9 bars and a pressure P2 of about 11 bars: the energy efficiency is therefore improved by 7.06%.

[0123] Similarly in the diagram of FIG. 7A, the energy efficiency is shown as a function of the pressure P3, and as a function of the various variants of the invention, in particular in the case of a neon nitrogen mixture. The points W0-W1-W2-W3-W4 correspond to the same power levels injected into the motor M1 as described previously with reference to FIGS. 5A-6A. P3 thus represents the maximum pressure of the system at the level of the circuit S3: it increases in proportion to the power injected, as well as to the percentage of neon in the refrigerant gas mixture.

[0124] Thus, an increase in the proportion of injected power W at the level of the motor M1 of FIIGS. 2 - 3 compared to the total injected power:

- has no influence on the pressure P1,
- increases the pressure P2
- increases the maximum pressure P3,
- decreases the energy consumption Ef to a minimum value, for a given proportion of power W, then this energy consumption increases again beyond this said given proportion of power W.

[0125] Likewise, the use of a nitrogen-neon mixture leads to an improvement in energy performance as shown in FIGS. 5A and 6A, both in the conventional methods described with reference to FIG. 1 and in the methods described in reference to FIGS. 2 - 3.

[0126] Thus, considering a mixture comprising 20% neon, the pressure P1 is approximately 12.5 bars and the curve 71 in FIG. 5A represents the variations in energy consumption for the same increasing powers supplied to the system at the level of the motor M3 (W4>W3>W2>W1>W0=0).

[0127] For this same neon percentage of 20%, on the curve 91 of FIG. 6A, the variations in energy consumption have been represented for the same increasing powers supplied to the system at the level of the motor M1 (W4>W3>W2>W1>W0=0), depending on the pressure P2. It is thus observed that when the power W injected at the level of M1 is increased, the efficiency increases, i.e. the energy consumption expressed in kWxd/t decreases, until reaching a minimum 91a, located between the points W2 and W3 of said curve 91, then said energy consumption increases again towards W4. This minimum corresponds to the low point 71a of the curve 71 in FIG. 5A, for a minimum energy consumption of approximately 19.4 kWxday/t, a pressure P1 of approximately 12,5 bars and a pressure P2 of approximately 33 bars. In comparison, the operating point W0 of the same curve 91 corresponding to a 20% mixture of neon, without energy input to the motor M1 corresponds to an energy consumption of approximately 20.45 kW x day/t, at a same pressure P1 of approximately 12.5 bars and a pressure P2 of approximately 17 bars, which illustrates the improvement in energy efficiency when the increase in the percentage of neon and the increase in the injected power are combined at motor M1.

[0128] The same effects are observed for hydrogen in FIGS 5B and 6B.

[0129] FIGS. 5 to 7 show performance diagrams of a conventional process and of the method according to the invention for liquefying a natural gas consisting of 85% methane, and 15% of said other constituents.

[0130] In the diagram of FIG. 7A, the maximum pressure P3 is represented on the abscissa and the energy per unit mass of gas is on the ordinate. Energy is represented in kW x day/ton of natural gas (1 kW x day/t = 0.024 kWh/kg). Thus, for a refrigerant gas consisting of 100% nitrogen, the operating point of the conventional process with reference to FIG. 1 is located at 60 in this FIG. 7A. On the other hand, in the method according to the invention with reference to FIGS. 2 and 3, for various nitrogen-neon mixture compositions, by injecting power into the motor M1, the efficiency of the installation can be varied according to the curve 70 (20% neon) and other curves (40 - 50% neon). Thus, from an operating point of 45-50 bars according to the conventional method, corresponding to an energy consumption of approximately 21.3 kW x d/t, the thermodynamic efficiency can be increased by increasing the maximum pressure. Thus, as shown in this same diagram, for a refrigerant gas consisting of 100% pure nitrogen, by injecting part of the power at the level of the motor M1, and by operating at a pressure of approximately 68 bars, the consumption in energy drops to around 19.75 kWxd/t, which represents an efficiency gain of 7.28%.

[0131] In general, by operating at higher pressure, for a given mass flow rate, the volume flow rates are reduced in proportion to the increase in said pressure: - the pipes are of smaller diameter, but their mechanical resistance, therefore their thickness, their weight and cost are increased by as much: - on the other hand, the footprint is reduced accordingly, which is very interesting in the case of installations in a confined environment such as on an anchored floating support at sea, or on a methane tanker in the case of a boil-off reliquefaction unit. Likewise, compressors and turbines operating at higher pressure are much more compact. With regard to cryogenic exchangers, the increase in pressure also improves heat transfers, but the heat exchange surfaces are not reduced in the same proportion as in the case of pipes and compressors and turbines. On the other hand, their weight increases significantly because they must resist this increase in pressure.

[0132] Thus, overall, the method according to the invention of FIGS. 2-3 leads to installations having greater compactness and to a significant improvement in energy efficiency when the refrigerant gas is pure nitrogen, said energy efficiency being further improved when the refrigerant gas is a mixture of nitrogen and either neon or hydrogen.

[0133] In FIG. 7A, there is shown a performance diagram of a conventional method with reference to FIG. 1, and of the method according to the invention of FIGS. 2-3 using as refrigerant gas a mixture of nitrogen and neon, in which the maximum pressure P3 is represented on the abscissa and the energy per unit mass of gas is on the ordinate. Energy is represented in kW x day/ton of natural gas (kW x d/t).

[0134] Thus, for a given composition of gas, the operating point of the conventional method with reference to FIG. 1 is located at 60 in this FIG. 7A. In the method according to the invention with reference to FIGS. 2 and 3, using a refrigerant gas composed of 100% nitrogen, by injecting power into the motor M1, the efficiency of the installation can be varied according to the curve 61 with an optimum operating point 62 at approximately 68 bars, corresponding to an energy consumption of approximately 19.75 kWxd/t, which represents an efficiency gain of 7.28% compared to the operating point 60 of the conventional process.

[0135] By using a mixture of 80% nitrogen and 20% neon as refrigerant gas, the pressure can be increased, as shown on the curve 70, without the gas mixture reaching its dew point, up to an optimum value 70a of approximately 88 bars and for a minimum energy consumption of approximately 19.4 kWxd/t, which represents a gain in thermodynamic efficiency of 1.77% compared to the operating point 62 of the method according to the invention with a refrigerant gas composed of 100% nitrogen and a thermodynamic efficiency gain of 8.92% compared to the operating point 60 of the conventional process.

[0136] By using a mixture of 60% nitrogen and 40% neon as refrigerant gas, the pressure can be increased, as shown on the curve 71, without the gas mixture reaching its dew point, up to an optimum value 71a of approximately 118 bars and for a minimum energy consumption of approximately 19.15 kWxd/t, which represents a gain in thermodynamic efficiency of 3.04% compared to the operating point 62 of the process according to the invention with a refrigerant

gas composed of 100% nitrogen and a thermodynamic efficiency gain of 10.09% compared to the operating point 60 of the conventional process.

[0137] By using a mixture of 50% nitrogen and 50% neon as refrigerant gas, the pressure can be increased, as shown on the curve 72, without the gas mixture reaching its dew point, up to an optimum value 72a of approximately 145 bars and for a minimum energy consumption of approximately 18.8 kWxd/t, which represents a gain in thermodynamic efficiency of 4.81% compared to the operating point 62 of the method according to the invention with a refrigerant gas composed of 100% nitrogen and a thermodynamic efficiency gain of 11.74% compared to the operating point 60 of the conventional process.

[0138] Likewise, as shown in the diagram of FIG. 7B, a mixture of nitrogen and hydrogen is advantageously used as refrigerant gas.

[0139] Thus, by using a mixture of 80% nitrogen and 20% hydrogen as refrigerant gas, the pressure can be increased, as shown on the curve 80, without the gas mixture reaching its dew point, up to an optimum value 80a of approximately 94 bars and for a minimum energy consumption of approximately 19.2 kWxd/t, which represents a gain in thermodynamic efficiency of 2.78% compared to the operating point 62 of the process according to invention of Figures 2-3 with a refrigerant gas composed of 100% nitrogen, and a thermodynamic efficiency gain of 9.86% compared to the operating point 60 of the conventional process of Figure 1.

[0140] By using a mixture of 60% nitrogen and 40% hydrogen as refrigerant gas, the pressure can be increased, as shown on the curve 81, without the gas mixture reaching its dew point, up to at an optimum value 81a of approximately 140 bars and for a minimum energy consumption of approximately 18.8 kWxd/t, which represents a gain in thermodynamic efficiency of 4.81% compared to the operating point 62 of the method according to the invention of figures 2-3 with a refrigerant gas composed of 100% nitrogen and a thermodynamic efficiency gain of 11.74% compared to the operating point 60 of the conventional process of figure 1.

[0141] By using a mixture of 50% nitrogen and 50% hydrogen as refrigerant gas, the pressure can be increased, as shown on the curve 82, without the gas mixture reaching its dew point, up to at an optimum value 82a of approximately 186 bars and for a minimum energy consumption of approximately 18.7 kWxd/t, which represents a gain in thermodynamic efficiency of 5.32%

compared to the operating point 62 of the method according to the invention of figures 2-3 with a refrigerant gas composed of 100% nitrogen and a thermodynamic efficiency gain of 12.21% compared to the operating point 60 of the conventional process of figure 1.

[0142] Thus, an increasing percentage of complementary gas, either hydrogen or neon, added to nitrogen to constitute a refrigerant gas, radically improves the thermodynamic efficiency of the process, while allowing operation at higher pressure, which implies more compact equipment, which is very advantageous when only very small surfaces are available, which is the case on a floating support anchored at sea, or on board an methane tanker, in the case of reliquefaction units.

[0143] Advantageously, the method according to the invention uses either a mixture of nitrogen and neon, or of nitrogen and hydrogen, and despite its slightly lower yield, the use of the mixture of nitrogen and neon will be preferred, because neon is an inert gas, while hydrogen is combustible and remains dangerous and difficult to operate, especially at high pressure in installations confined on board a floating medium. In addition, hydrogen is a gas which percolates very easily through elastomeric seals and even in certain cases through metals, especially at very high pressure, and therefore the process according to the invention based on the use of a nitrogen-hydrogen mixture does not constitute the preferred version of the invention: the preferred version of the invention remains the use as refrigerant gas of a mixture of nitrogen and neon in the devices described with reference to the various figures.

[0144] In the same way, the yield of the conventional processes using nitrogen as refrigerant gas is improved, by considering a binary nitrogen-neon or nitrogen-hydrogen mixture, which, on the other hand, does not form the subject of the present invention.

[0145] Thus, as represented in the diagram of FIG. 7A, the curve 75 represents the variation in the yield of a conventional process according to FIG. 1, or of its variants, as a function of the percentage of neon gas in the refrigerant gas. For a percentage of 20% neon, the operating point is at 70b, which corresponds to a maximum pressure P3 of approximately 63 bars and an energy consumption of approximately 20.45 kWxd/t, which represents a gain in efficiency thermodynamic of 3.76% compared to the operating point 60 of the same conventional process with a refrigerant gas composed of 100% nitrogen.

[0146] For a percentage of 40% neon, the operating point is at 71b, which corresponds to a maximum pressure P3 of approximately 90 bars and an energy consumption of approximately 19.70 kWxd/t, which represents a gain in efficiency thermodynamic of 7.29% compared to the operating point 60 of the same conventional method with a refrigerant gas composed of 100% nitrogen.

[0147] For a percentage of 50% neon, the operating point is at 72b, which corresponds to a maximum pressure P3 of approximately 120 bars and an energy consumption of approximately 19.35 kWxd/t, which represents a gain in efficiency thermodynamic of 8.94% compared to the operating point 60 of the same conventional method with a refrigerant gas composed of 100% nitrogen.

[0148] In the same way with a nitrogen-hydrogen mixture comprising 20% hydrogen, as represented in FIG. 7B, the operating point is located at 80b, which corresponds to a maximum pressure P3 of approximately 68 bars and a consumption of energy of about 20.2 kWxd/t, which represents a gain in thermodynamic efficiency of 4.94% compared to the operating point 60 of the same conventional method with a refrigerant gas composed of 100% nitrogen.

[0149] For a percentage of 40% hydrogen, the operating point is at 81b, which corresponds to a maximum pressure P3 of approximately 108 bars and an energy consumption of approximately 19.8 kWxd/t, which represents a gain of thermodynamic efficiency of 6.82% compared to the operating point 60 of the same conventional method with a refrigerant gas composed of 100% nitrogen.

[0150] For a percentage of 50% hydrogen, the operating point is at 82b, which corresponds to a maximum pressure P3 of approximately 150 bars and an energy consumption of approximately 19 kWxd/t, which represents a gain of thermodynamic efficiency of 10.59% compared to the operating point 60 of the same conventional method with a refrigerant gas composed of 100% nitrogen.

[0151] By way of example, a conventional liquefaction unit is dimensioned in relation to the powers of the gas turbines available, the high power turbines being commonly 25MW.

[0152] One generally seek to increase the power of the installation, and it is then possible to install two identical gas turbines (GT1 and GT2) in parallel to obtain 30MW (2x15MW), or even 40MW (2x20MW), but we then have two lines of rotating machines, which increases the overall dimensions, the quantities of pipes and of course the costs.

[0153] By installing a single 25MW GT turbine in C3 as in Figure 2 and adding power to the second M2 motor, for example 5MW, to obtain a total of 30MW, or 15MW to obtain a total of 40MW, the operation of the method with reference to FIG. 2 is identical in terms of efficiency to that using two gas turbines (GT1 and GT2) in parallel.

[0154] Thus, considering a GT gas turbine of 25MW, the addition of 5MW of power at the level of the motor (M2), preferably thanks to an electric motor, gives more flexibility in operation and thus allows an increase in power of 20%. On the other hand, the efficiency of the whole remains unchanged, substantially at 21.25 kW x day/t of LNG produced as shown in the diagram of FIG. 7 at point 60.

[0155] If, on the other hand, the same power of 5MW is supplied to the level of the first motor M1, the overall power is still 30MW, but in this case the efficiency of the assembly is improved and significantly reaches the value of 19.8 kW x day/t of LNG produced, which represents a gain of 6.59% for the same overall power of 30MW, compared to a power injection of 5MW at the level of the second motor M2, as detailed previously. Said power input of 5 MW to the first motor M1 then represents 16.6% of the overall power and said efficiency (19.8 kW x day/t) corresponds substantially to point W2 of the diagram of FIG. 7.

[0156] In the same way in figure 3, by installing a single GT turbine of 25MW in C2 as in figure 3 and by adding power at the level of the GT turbine, for example 5MW to obtain a total of 30MW, or 10MW for obtain a total of 40MW, the operation of the process with reference to FIG. 2 is identical in terms of efficiency to that using two gas turbines (GT1 and GT2) in parallel.

[0157] Thus, considering a GT gas turbine of 25MW, the addition of 5MW of power at the level of the GT turbine, gives more flexibility in operation and thus allows a power increase of 20%. On the other hand, the efficiency of the whole remains unchanged, substantially at 21.25 kW x day/t of LNG produced as shown in the diagram of FIG. 7 at point 60.

[0158] If, on the other hand, the same power of 5MW is supplied to the level of the first motor M1, the overall power is still 30MW, but in this case the efficiency of the assembly is improved and significantly reaches the value of 19.8 kW x day/t of LNG produced, which represents a gain of 6.59% for the same overall power of 30MW, compared to a power injection of 5MW at the level of the second motor M2, as detailed previously. Said power input of 5 MW to the first motor M1 then represents 16.6% of the overall power and said efficiency (19.8 kW x day/t) corresponds substantially to point W2 of the diagram of FIG. 7.

[0159] Thus, depending on the production of natural gas, both in quantity and quality, from groundwater, a GT gas turbine, for example of 25MW, will advantageously be used at full speed continuously,

- which will be completed by power injection at the level of the GT turbine (FIG. 3) or of the second M2 motor (FIG. 2) without changing the overall efficiency (point WO of FIG. 7), and
- which will be supplemented, or even if necessary modulated, by power injection at the level of the first motor M1, which has the effect of improving the overall efficiency according to the curve 61 of the same FIG. 7, until an optimum is reached, that is to say a minimum energy consumption of 19.75 kW x day/t corresponding substantially to point W3 of said curve 61: - the energy injected into said first motor M1 then representing in this case substantially 24% of the total energy.

[0160] In general, we will operate with a gas turbine GT at full speed, which will be completed by a power supply to the first motor M1, said input being limited to about 24% of the overall power so as to optimize the output to the minimum value of 19.75 kW x day/t, then if necessary, the overall power will be increased by power injection at the level of the second motor M2, and concomitantly the power injected at the level of the first motor M1 will be readjusted, so that said power is always substantially equal to approximately 24% of the overall power so as to keep the efficiency of the installation at the optimum value of 19.75 kW x day/t.

[0161] Said optimum efficiency of 19.75 kW x day/t for a power of the first motor M1 representing 24% of the total power is valid for a refrigerant fluid consisting of 100% nitrogen. In the case of nitrogen-neon or nitrogen-hydrogen mixtures, the optimum efficiency as well as

the power percentage vary depending on the mixtures and the percentages of neon or hydrogen, but the advantages detailed previously remain valid and even accumulate.

Patentkrav

1. Fremgangsmåde til kondensation af en naturgas, omfattende overvejende methan, fortrinsvis mindst 85% methan, hvor de andre komponenter i det væsentlige omfatter nitrogen og C2-C4-alkaner, hvor der kondenseres den naturgas, der skal kondenseres, ved cirkulation af naturgassen ved et tryk P0, der er større end eller lig med det atmosfæriske tryk (Patm), fortrinsvis er P0 større end atmosfærisk tryk, i mindst én kryogen varmeveksler (EC1, EC2, EC3) ved lukket modstrømskredsløbscirkulation i indirekte kontakt med mindst én strøm af kølegas, som forbliver i den gasformige tilstand, komprimeres ved et tryk P1, kommer ind i den kryogene veksler ved en temperatur T3', der er lavere end T3, hvor T3 er kondensationstemperaturen for den kondenserede naturgas ved udløbet af den kryogene veksler, hvor T3 er lavere end eller lig med kondensationstemperaturen for den kondenserede naturgas ved atmosfærisk tryk, hvor der kondenseres den naturgas, der skal kondenseres, ved at udføre de følgende samtidige trin med:

(a) cirkulation af den naturgas, der skal kondenseres, og som cirkulerer (Sg) ved et tryk P0, der er større end eller lig med atmosfærisk tryk (Patm), fortrinsvis hvor P0 er større end atmosfærisk tryk, i mindst tre kryogene varmevekslere (EC1, EC2, EC3), der er arrangeret i serie, hvoraf:

- en første veksler (EC1), hvor den naturgas, der kommer ind ved en temperatur T0, afkøles og kommer ud (BB) ved en temperatur T1, der er lavere end T0, derefter
- en anden veksler (EC2), hvor naturgassen er fuldstændigt kondenseret og kommer ud (CC) ved en temperatur T2, der er lavere end T1 og større end T3, og
- en tredje veksler (EC3), hvor den kondenserede naturgas afkøles fra T2 til T3, og

(b) cirkulation i et lukket kredsløb af mindst to strømme (S1, S3) af kølegas i gasform, som kaldes henholdsvis første og tredje strøm ved forskellige tryk P1

og P2, der passerer gennem mindst nævnte to vekslere i indirekte kontakt med og i modstrøm af naturgasstrømmen (Sg), omfattende:

- den første strøm af kølegas (S1) ved et tryk P1, der er lavere end P3, der passerer gennem de tre vekslere (EC1, EC2, EC3), kommer ind (DD) i den tredje veksler (EC3) ved en temperatur T3', der er lavere end T3, hvorefter den kommer ind (CC) ved en temperatur T2', der er lavere end T2 i den anden veksler (EC2), dernæst ind i (BB) ved en temperatur T1', der er lavere end T1 i den første veksler (EC1) og forlader (AA) af den første veksler ved en temperatur T0', der er lavere end eller lig med T0, hvor den første strøm af kølegas ved P1 og T3' opnås ved ekspansion i mindst én første ekspander (E1) af en første del (D1) af en anden strøm (S2) af kølegas, der komprimeres ved trykket P3, der er større end P2, hvor den anden strøm (S2) cirkulerer i indirekte kontakt med og i medstrøm af naturgasstrømmen (Sg) ved at komme ind (AA) i den første veksler (EC1) ved T0, og den første del (D1) af den anden strøm (S2) forlader (CC) den anden veksler (EC2) i det væsentlige ved T2, og

- den tredje strøm (S3) ved et tryk P2 større end P1 og lavere end P3, der cirkulerer i indirekte kontakt med og medstrøm af den første strøm, der kun passerer gennem den anden og første veksler (EC2, EC1), der går ind i (CC) den anden veksler ved en temperatur T2' der er lavere end T2 og forlader (AA) af den første veksler (EC1) ved T0', der er lavere end eller lig med T0, hvor den tredje strøm (S3) af kølegas ved P2 og T2 opnås ved ekspansion i en anden ekspander (E2) af en anden del (D2) af den anden strøm (S2) af kølegas, der i det væsentlige forlader den første veksler ved T1, hvor strømningshastigheden D2 af den anden del af den anden strøm fortrinsvis er større end strømningshastigheden D1 af første del af anden strøm,

(c) hvor den anden strøm af kølegas (S2), der komprimeres ved trykket P3, opnås ved komprimering med mindst to kompressorer (C1, C2, C3) og afkøling (H1, H2) af den første og tredje strøm (S1, S3) af kølegas, der forlader (AA) den første veksler (EC1) ved henholdsvis P1 og P2,

hvor en første kompressor komprimerer fra P1 til P2 hele den første strøm af kølegas, der forlader (AA) af den første veksler (EC1), og mindst af den anden kompressor (C2), der komprimerer fra P2 til mindst P'3, hvor P'3 er et tryk, der er lavere end eller lig med P3 og større end P2, på den ene side den tredje strøm (S3) af kølegas, der forlader den første veksler (EC1) ved P2, og på den anden side den første strøm af kølegas, der komprimeres ved P2 og forlader den første kompressor, for at opnå den anden strøm af kølegas ved P3 og T0 efter afkøling (H1, H2),

i hvilken fremgangsmåde:

- både første og anden kompressor (C1, C2), der er anbragt i serie, er henholdsvis koblet til den første og anden ekspander (E1, E2), der består af energigenvindingsmøller, og
- mindst den første kompressor (C1) er koblet til en første motor (M1),

hvor fremgangsmåden er **kendetegnet ved, at**:

- den første motor gør det muligt at modulere og kontrollere specifikt værdien af trykket P2 ved at tilvejebringe en differentieret effekt til den første kompressor i forhold til den effekt, der tilføres de andre kompressorer, og
- en gasturbine (GT) er koblet til enten den anden kompressor, hvor denne komprimerer den anden strøm af kølegas direkte ved P3, eller til en tredje kompressor (C3), der er seriemonteret efter den anden kompressor (C2), hvor den tredje kompressor komprimerer fra P'3 til P3 den anden strøm af kølegas,
- den første motor (M1) tilvejebringer mindst 3%, fortrinsvis fra 3 til 30%, af den samlede effekt, der tilføres alle de implementerede kompressorer (C1, C2), hvor gasturbinen (GT) tilvejebringer 97 til 70% af total effekt, der tilføres alle de implementerede kompressorer (C1, C2, C3).

2. Fremgangsmåde ifølge krav 1, **kendetegnet ved, at** trykket P2 varieres på en kontrolleret måde ved at levere effekt på en kontrolleret måde til den første

kompressor med den første motor på en sådan måde, at den energi, der forbruges ved udførelse af fremgangsmåden (Ef) er minimal.

3. Fremgangsmåde ifølge krav 2, **kendetegnet ved, at** trykket P2 øges ved at forøge den effekt, der injiceres til den første kompressor med den første motor, hvor trykket P1 forbliver i det væsentlige konstant.

4. Fremgangsmåde ifølge krav 2 eller 3, **kendetegnet ved, at** trykket P2 varieres på en kontrolleret måde ved at levere effekt på en kontrolleret måde til den første kompressor med den første motor, når sammensætningen af den naturgas, der skal kondenseres, varierer.

5. Fremgangsmåde ifølge et af kravene 1 til 4, **kendetegnet ved, at** der anvendes to kompressorer (C1, C2), der er seriemonterede og omfatter:
(i) den første kompressor, der er koblet til den første ekspander (E1), der komprimerer fra P1 til P2 hele den første strøm af kølegas, der forlader (AA) af den første veksler (EC1), og
(ii) den anden kompressor (C2), der er koblet til den anden ekspander (E2) og komprimerer fra P2 til P3 på den ene side den tredje strøm (S3) af kølegas, der forlader den første veksler (EC1) ved P2, og på den anden side den første strøm af kølegas, der komprimeres ved P2 og forlader den første kompressor, for at opnå den anden strøm af kølegas (S2) ved P3 og T0 efter afkøling (H1, H2), og
(iii) den første kompressor (C1) drives af den første motor (M1), hvor den anden kompressor (C2) drives af i det mindste gasturbinen (GT).

6. Fremgangsmåde ifølge et af kravene 1 til 4, **kendetegnet ved, at** der anvendes tre kompressorer (C1, C2, C3), der er seriemonterede og omfatter:

(i) den første kompressor (C1), der er drevet af den første motor (M1) og koblet til den første ekspander (E1), der komprimerer fra P1 til P2 hele den første strøm af kølegas, der forlader (AA) af den første veksler (EC1), og

(ii) den anden kompressor (C2), der er drevet af den anden motor (M2) og koblet til den anden ekspander (E2), der komprimerer fra P2 til P'3, hvor P'3 er større end P2 og mindre end P3, på den ene side den tredje strøm (S3) af kølegas, der forlader den første veksler (EC1) ved P2, og på den anden side den første strøm af kølegas, der komprimeres ved P2 og forlader den første kompressor C1, og

(iii) den tredje kompressor (C3), der er drevet af gasturbinen (GT) for at tilvejebringe det meste af energien og komprimere ved P3, al den første og tredje strøm af kølegas ved P3 og T0 efter afkøling (H1, H2), og

(iv) den første motor (M1) tilvejebringer mindst 3%, fortrinsvis fra 3 til 30%, af den samlede effekt, der tilføres alle de implementerede kompressorer (C1, C2, C3), hvor gasturbinen (GT), der er koblet til den tredje kompressor (C3), samt den anden motor (M2), der er koblet til den anden kompressor (C2), tilvejebringer 97 til 70% af total effekt, der tilføres alle de implementerede kompressorer (C1, C2, C3).

7. Fremgangsmåde ifølge et af kravene 1 til 6, **kendetegnet ved, at** kølegassen omfatter nitrogen.

8. Fremgangsmåde ifølge et af kravene 1 til 7, **kendetegnet ved, at** sammensætningen af den gas, der skal kondenseres, er inden for de følgende intervaller med totalsum på 100%:

- methan fra 80 til 100%,
- nitrogen fra 0 til 20%,
- ethan fra 0 til 20%,
- propan fra 0 til 20%, og
- butan fra 0 til 20%.

9. Fremgangsmåde ifølge et af kravene 1 til 8, **kendetegnet ved, at**:

- T0 og T0' er fra 10 til 35°C, og
- T3 og T3' er fra -160 til -170°C, og
- T2 og T2' er fra -100 til 140°C, og
- T1 og T1' er fra -30 til -70°C.

10. Fremgangsmåde ifølge et af kravene 1 til 9, **kendetegnet ved, at**:

- P0 er fra 0,5 til 5 MPa, og
- P1 er fra 0,5 til 5 MPa, og
- P2 er fra 1 til 10 MPa, og
- P3 er fra 5 til 20 MPa.

11. Fremgangsmåde ifølge et af kravene 1 til 10, **kendetegnet ved, at** P2 varieres, indtil den minimale samlede energi Ef, der forbruges i fremgangsmåden, er mindre end 21,5 kW x dag/t produceret flydende gas, fortrinsvis fra 18,5 til 20,5 kW x dag/t.

12. Fremgangsmåde ifølge kravene 1 til 11, **kendetegnet ved, at** den udføres ombord på en flydende understøtning..

13. Fremgangsmåde ifølge et af kravene 1 til 12, **kendetegnet ved, at** den anvender en binær blanding af nitrogen-neon eller nitrogen-hydrogen.

14. Ombordværende anlæg på en flydende understøtning til udførelse af en fremgangsmåde ifølge et hvilket som helst af kravene 1 til 13, hvor anlægget omfatter:

- mindst tre kryogene varmevekslere (EC1, EC2, EC3) i serie, der mindst omfatter:

- en første modstrømscirkulationskanal, der er i stand til at cirkulere en første strøm (S1) af kølegas i gasformig tilstand, der komprimeres ved P1, og successivt passerer i modstrøm gennem de 3 tredje, anden og første vekslere (EC3, EC2, EC1),
- en anden medstrømscirkulationskanal, der er i stand til at cirkulere en anden strøm (S2) af kølegas i gasformig tilstand, der komprimeres ved P3, og successivt passerer i medstrøm gennem kun den første og anden veksler (EC1, EC2),
- en tredje modstrømscirkulationskanal af kølegassen, der er i stand til at cirkulere en tredje strøm (S3) af kølegas i gasformig tilstand, der komprimeres ved P2, og successivt passerer i modstrøm gennem kun de anden og første veksler (EC2, EC1),
- en fjerde kanal (Sg), der er i stand til at cirkulere den naturgas, der skal kondenseres, og som successivt passerer gennem de tre første, anden og tredje vekslere (EC1, EC2, EC3),
- en første ekspander (E1) mellem udløbet af den anden kanal og indløbet til den første kanal,
- en anden ekspander (E2) mellem (i) en afledning (BB) af den anden kanal, som er placeret mellem den første og anden veksler og (ii) indløbet (CC) af den tredje kanal, og
- en første kompressor (C1) ved udløbet af den første kanal, som er koblet til en turbine, der består af den første ekspander,
- en anden kompressor (C2) ved udløbet af den tredje kanal, som er koblet til en turbine, der består af den anden ekspander, og den anden kompressor er seriemonteret med den første kompressor, og
- en kanal til cirkulation af al komprimeret gas ved P2 med den første kompressor (C1) til den anden kompressor (C2), der således er seriemonteret med den første kompressor, og
- mindst én første motor (M1), der er koblet til den første kompressor (C1),

kendetegnet ved, at den første motor er i stand til at tilvejebringe mindst 3%,

fortrinsvis fra 3 til 30%, af den samlede effekt, der leveres til alle implementerede kompressorer (C1, C2, C3), hvor den første motor gør det muligt at modulere og kontrollere specifikt værdien af trykket P2 ved at tilvejebringe en differentieret effekt til den første kompressor i forhold til den effekt, der tilføres de andre kompressorer, og

- en gasturbine (GT), der er koblet til enten den anden kompressor, hvor denne komprimerer den anden strøm af kølegas direkte ved P3, eller til en tredje kompressor (C3), der er seriemonteret efter den anden kompressor (C2), hvor den tredje kompressor komprimerer fra P'3 til P3 den anden strøm af kølegas, hvor gasturbinen er i stand til at levere fra 97 til 70% af den samlede effekt, der leveres til alle de implementerede kompressorer (C1, C2, C3).

15. Anlæg ifølge krav 14, **kendetegnet ved, at** det kun omfatter to kompressorer (C1, C2), der er seriemonteret, omfattende:

(i) den første kompressor (C1), der er koblet til den første ekspander (E1), der er i stand til at komprimere fra P1 til P2 hele den første strøm af kølegas, der forlader (AA) af den første veksler (EC1), og

(ii) den anden kompressor (C2), der er koblet til den anden ekspander (E2) og i stand til at komprimere fra P2 til mindst P'3, hvor P'3 er et tryk, der er større end P2 og mindre end eller lig med P3, på den ene side den tredje strøm (S3) af kølegas, der forlader den første veksler (EC1) ved P2, og på den anden side den første strøm af kølegas, der komprimeres ved P2 og forlader den første kompressor, for at opnå den anden strøm af kølegas ved P3 og T0 efter afkøling (H1, H2), og

(iii) den første motor (M1), der er koblet til den første kompressor (C1), og i det mindste gasturbinen (GT), der er koblet til den anden kompressor (C2), hvilken første motor er i stand til at tilvejebringe mindst 3%, fortrinsvis fra 3 til 30% af den samlede effekt, der leveres til alle de implementerede kompressorer (C1, C2), og

(iv) gasturbinen (GT), der er koblet til den anden kompressor og er i stand til at levere fra 97 til 70% af den samlede leverede effekt.

16. Anlæg ifølge krav 14, **kendetegnet ved, at** det kun omfatter tre kompressorer (C1, C2, C3), der er seriemonteret, omfattende:
(i) den første kompressor (C1), der er koblet til den første ekspander (E1) og til den første motor (M1), og
(ii) den anden kompressor (C2), der er koblet til den anden ekspander (E2) og til en anden motor (M2), og
(iii) den tredje kompressor (C2), der er koblet til gasturbinen (GT) og i stand til at tilvejebringe det meste af energien og i stand til at komprimere ved P3, al den første og tredje strøm af kølegas, der komprimeres af den anden kompressor (C2), for at opnå den anden strøm af kølegas ved P2 og T0 efter afkøling (H1, H2), og
(iv) den første motor (M1), der er i stand til at tilvejebringe mindst 3%, fortrinsvis fra 3 til 30% af den samlede effekt, der leveres til alle de implementerede kompressorer (C1, C2, C3), og
(v) gasturbinen (GT), der er koblet til den tredje kompressor (C3), samt den anden motor (M2), der er koblet til den anden kompressor (C2), er i stand til at tilvejebringe 97 til 70% af den samlede effekt, der tilføres alle de implementerede kompressorer (C1, C2, C3).

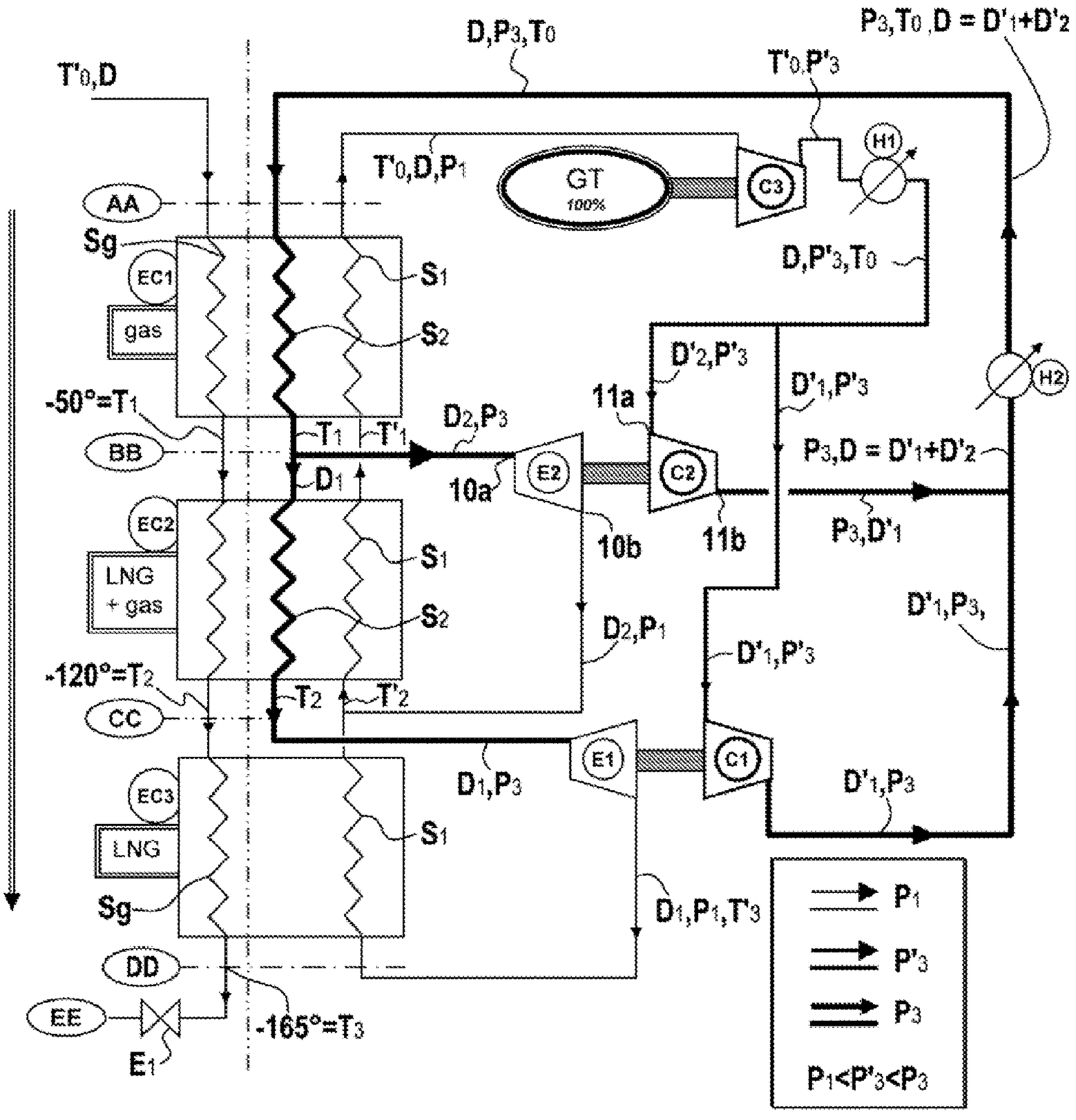
D,P3,T0
P3,T0 ,D = D'1+D'2
T'0,D
T'0,P'3
T'0,D,P1
GT
100%
C3
H1
AA
Sg
EC1
gas
S1
S2
D,P'3,T0
D'2,P'3
D'1,P'3
H2
-50°=T1
BB
T1
T'1
D2,P3
11a
P3,D = D'1+D'2
D1
10a
E2
C2
EC2
LNG
+ gas
10b
11b
P3,D'1
S1
S2
D2,P1
D'1,P3,
D'1,P'3
-120°=T2
T2
T'2
CC
E1
C1
D1,P3
D'1,P3
EC3
LNG
S1
Sg
D1,P1,T'3
P1
P'3
P3
P1<P'3<P3
DD
EE
-165°=T3
E1

FIG.1

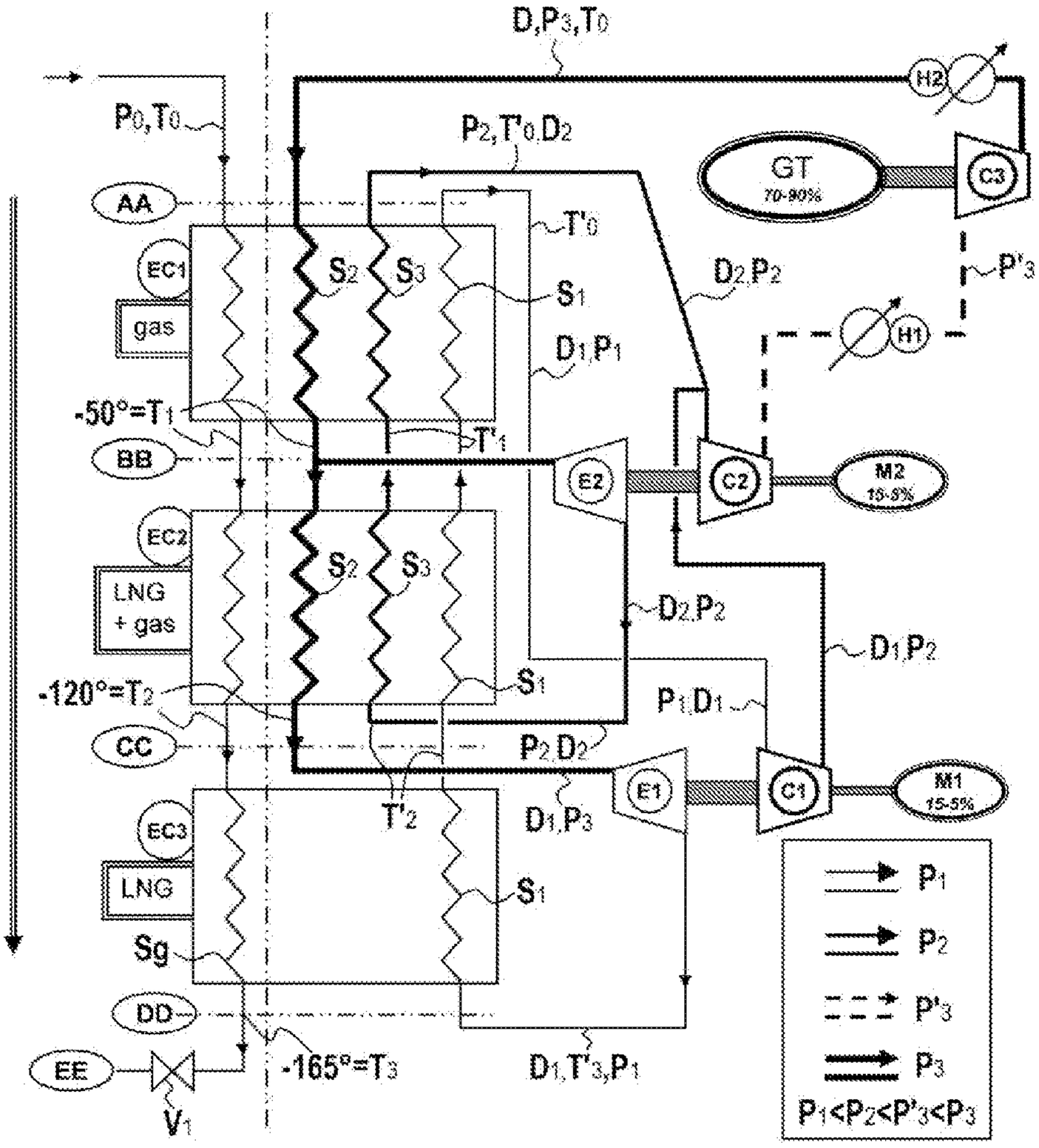
D,P3,T0
H2
P0,T0
P2,T'0,D2
GT
70-90%
C3
AA
T'0
EC1
S2
S3
S1
D2,P2
P'3
gas
D1,P1
H1
-50°=T1
T'1
BB
E2
C2
M2
15-5%
EC2
S2
S3
D2,P2
LNG
+ gas
D1,P2
S1
-120°=T2
P1,D1
CC
P2,D2
E1
C1
M1
15-5%
T'2
D1,P3
EC3
LNG
S1
Sg
P1
P2
P'3
P3
P1<P2<P'3<P3
DD
EE
-165°=T3
D1,T'3,P1
V1

FIG.2

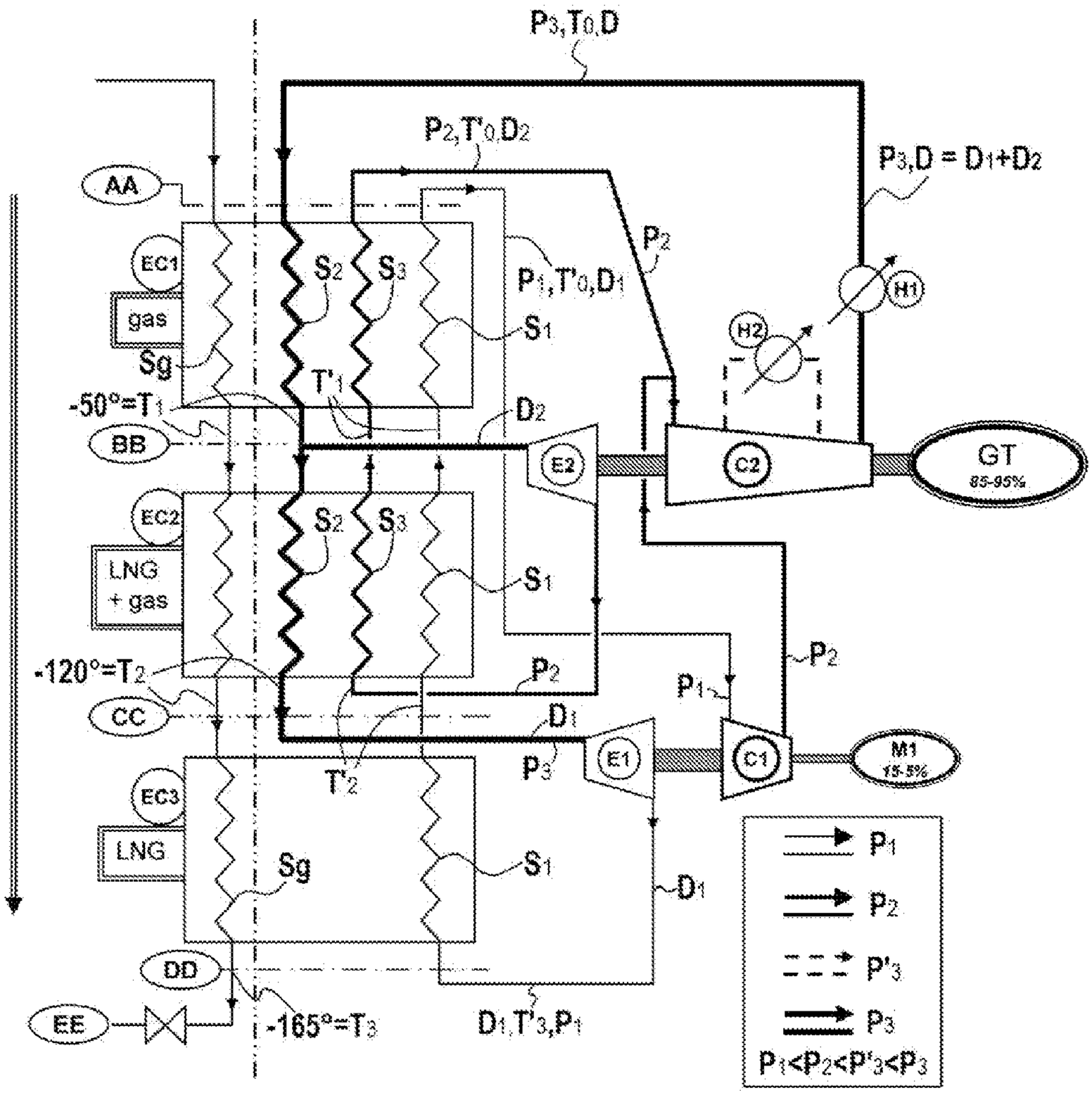
P3,T0,D
P2,T'0,D2
P3,D = D1+D2
AA
EC1
gas
Sg
S2
S3
P1,T'0,D1
P2
S1
H1
H2
T'1
-50°=T1
D2
BB
E2
C2
GT
85-95%
EC2
LNG
+ gas
S2
S3
S1
-120°=T2
P2
P1
P2
CC
D1
P3
E1
C1
M1
15-5%
T'2
EC3
LNG
Sg
S1
D1
DD
EE
-165°=T3
D1,T'3,P1
P1
P2
P'3
P3
P1<P2<P'3<P3

FIG.3

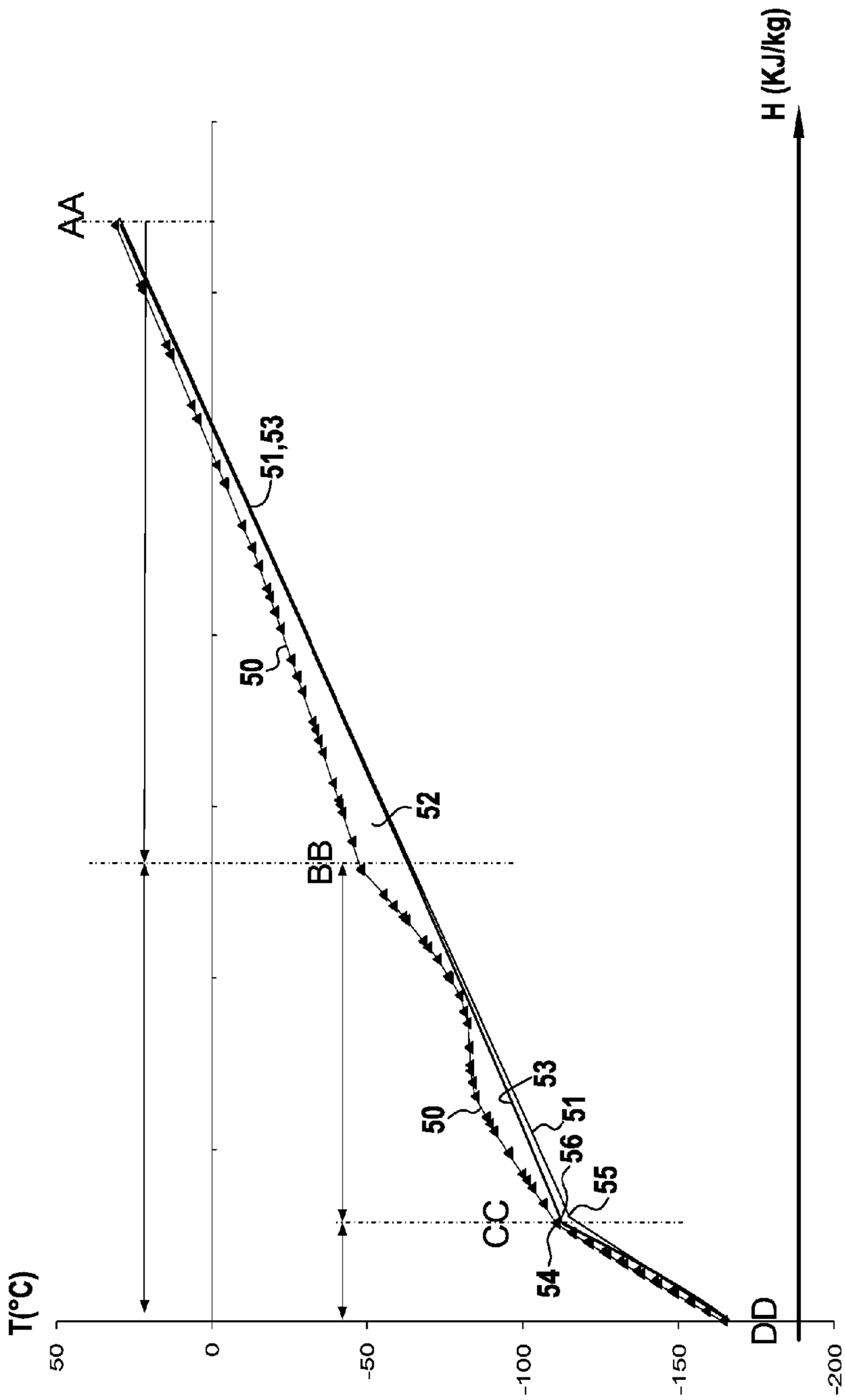
H (KJ/kg)
T(°C)
AA
BB
CC
DD
50
51
52
53
54
55
56
50
50
51,53
50
0
-50
-100
-150
-200

FIG.4

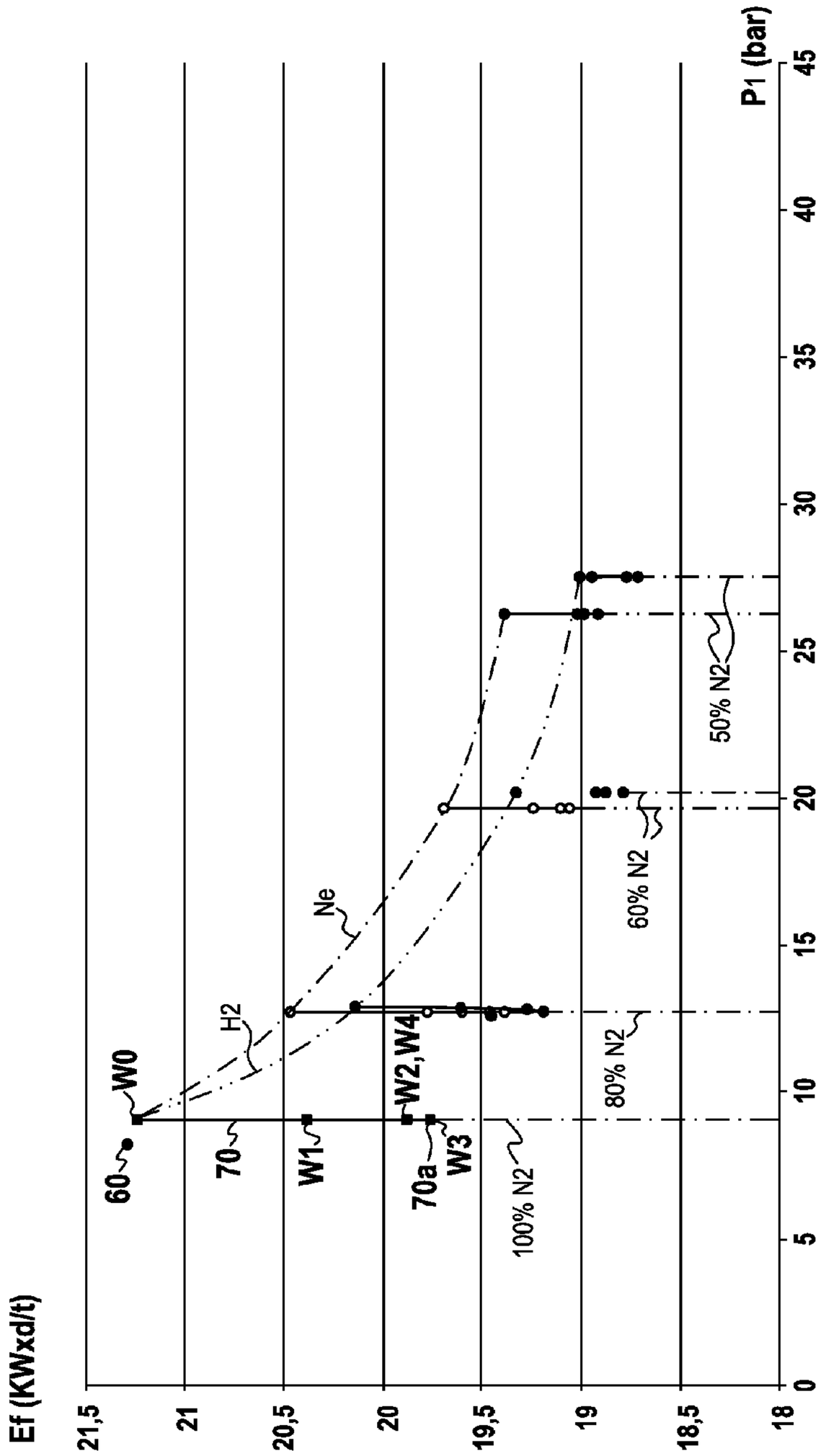
Ef (KWxd/t)
21,5
21
20,5
20
19,5
19
18,5
18
P1 (bar)
45
40
35
30
25
20
15
10
5
0
60
70
W0
W1
70a
W2,W4
W3
H2
Ne
100% N2
80% N2
60% N2
50% N2

FIG.5

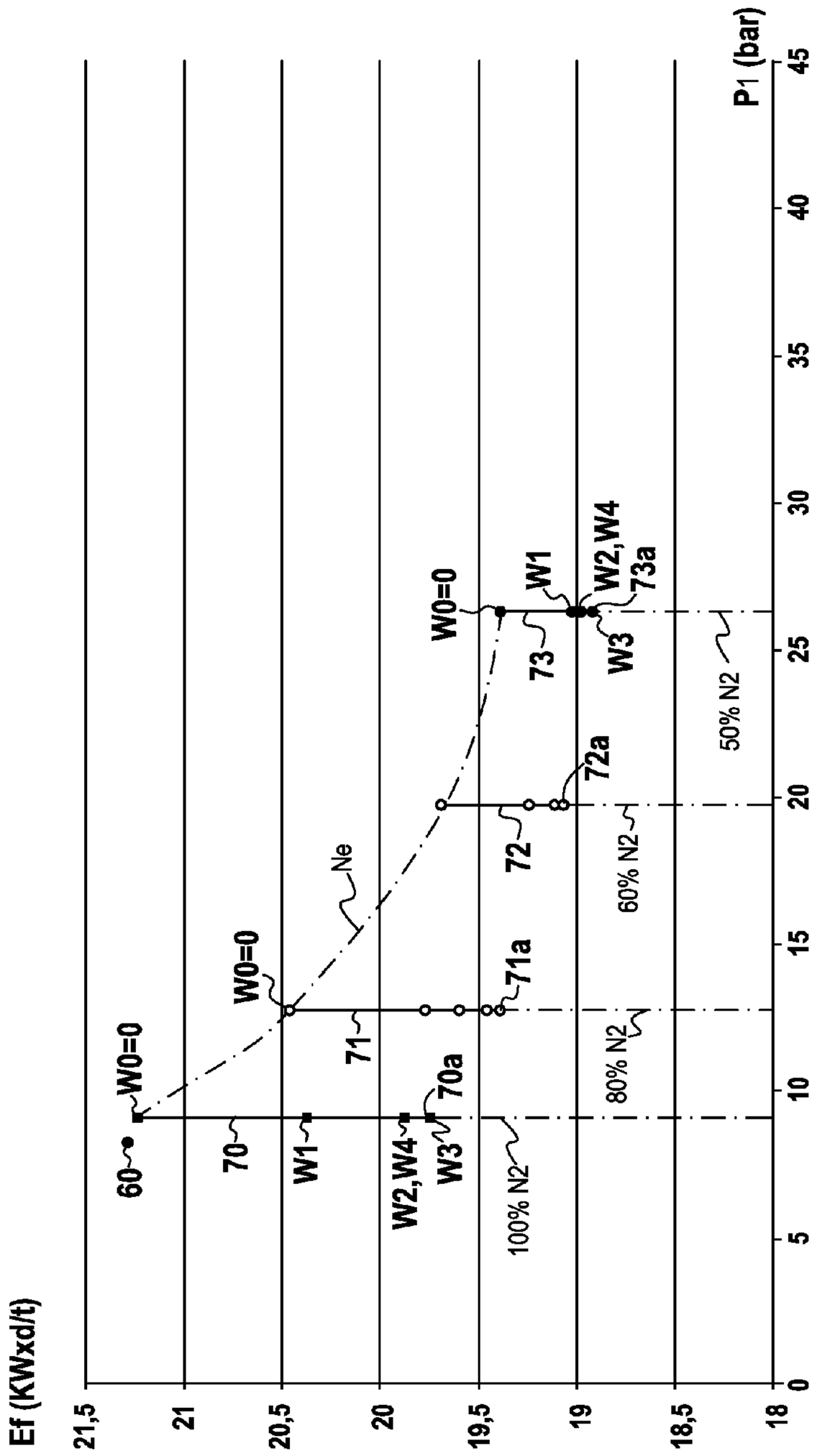
Ef (KWxd/t)
21,5
21
20,5
20
19,5
19
18,5
18
P1 (bar)
45
40
35
30
25
20
15
10
5
0
60
W0=0
70
W1
W2,W4
W3
70a
71
W0=0
71a
100% N2
80% N2
60% N2
50% N2
Ne
72
72a
73
W1
W2,W4
W3
73a

FIG.5A

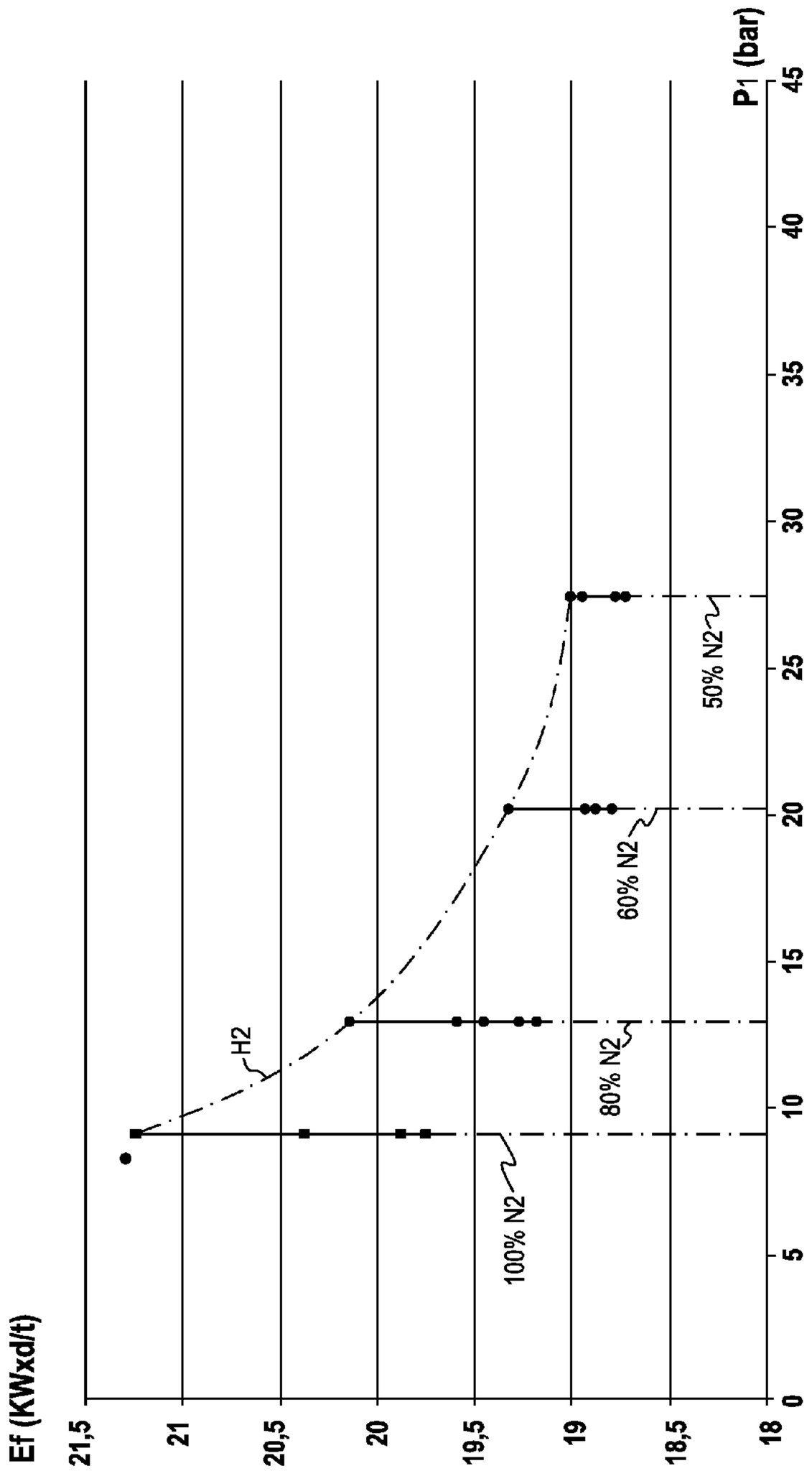
P1 (bar)
45
40
35
30
25
20
15
10
5
0
H2
100% N2
80% N2
60% N2
50% N2
Ef (KWxd/t)
21,5
21
20,5
20
19,5
19
18,5
18

FIG.5B

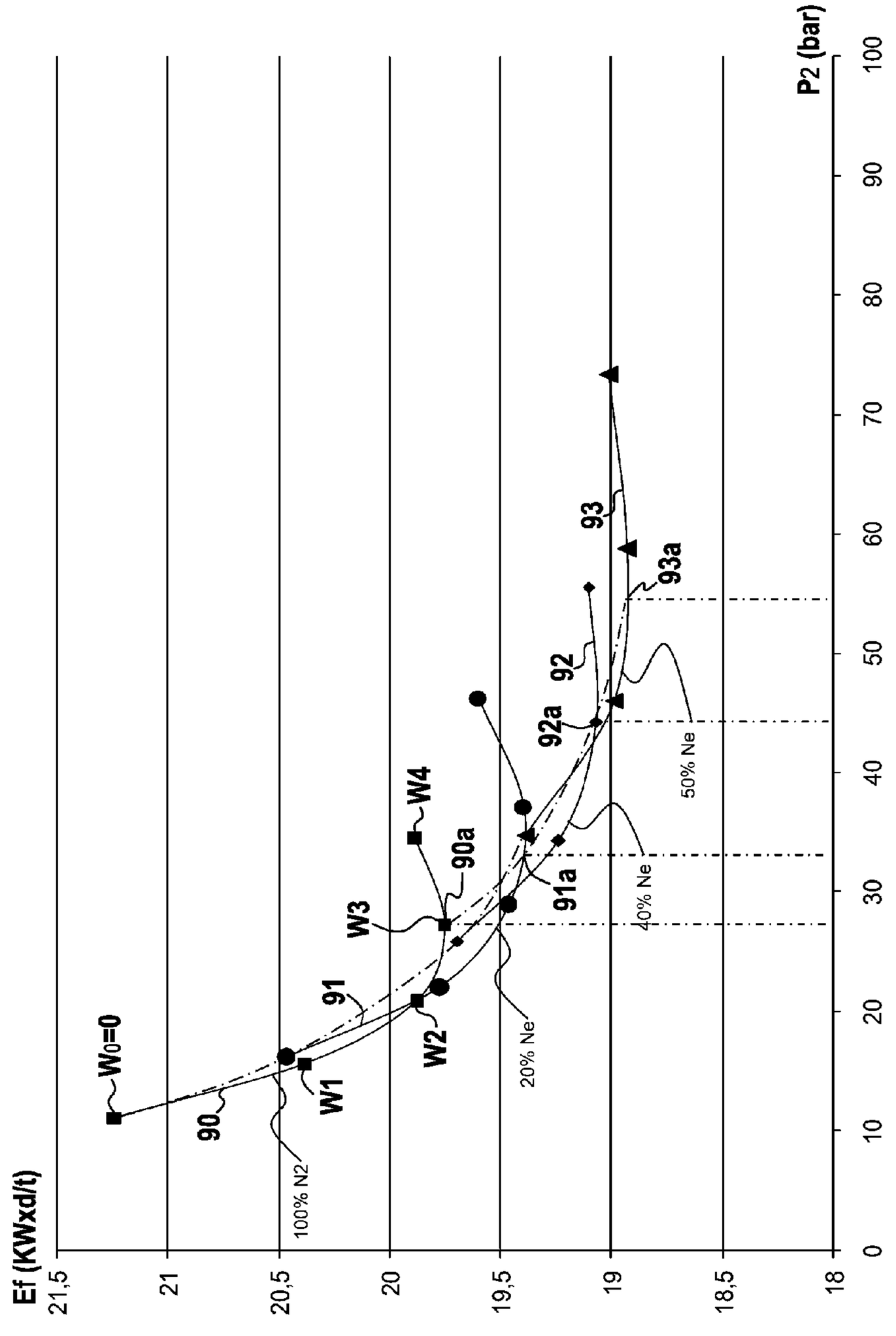
Ef (KWxd/t)
21,5
21
20,5
20
19,5
19
18,5
18
P2 (bar)
100
90
80
70
60
50
40
30
20
10
0
W0=0
90
100% N2
W1
91
W2
W3
W4
90a
20% Ne
91a
92
92a
40% Ne
93
93a
50% Ne

FIG.6A

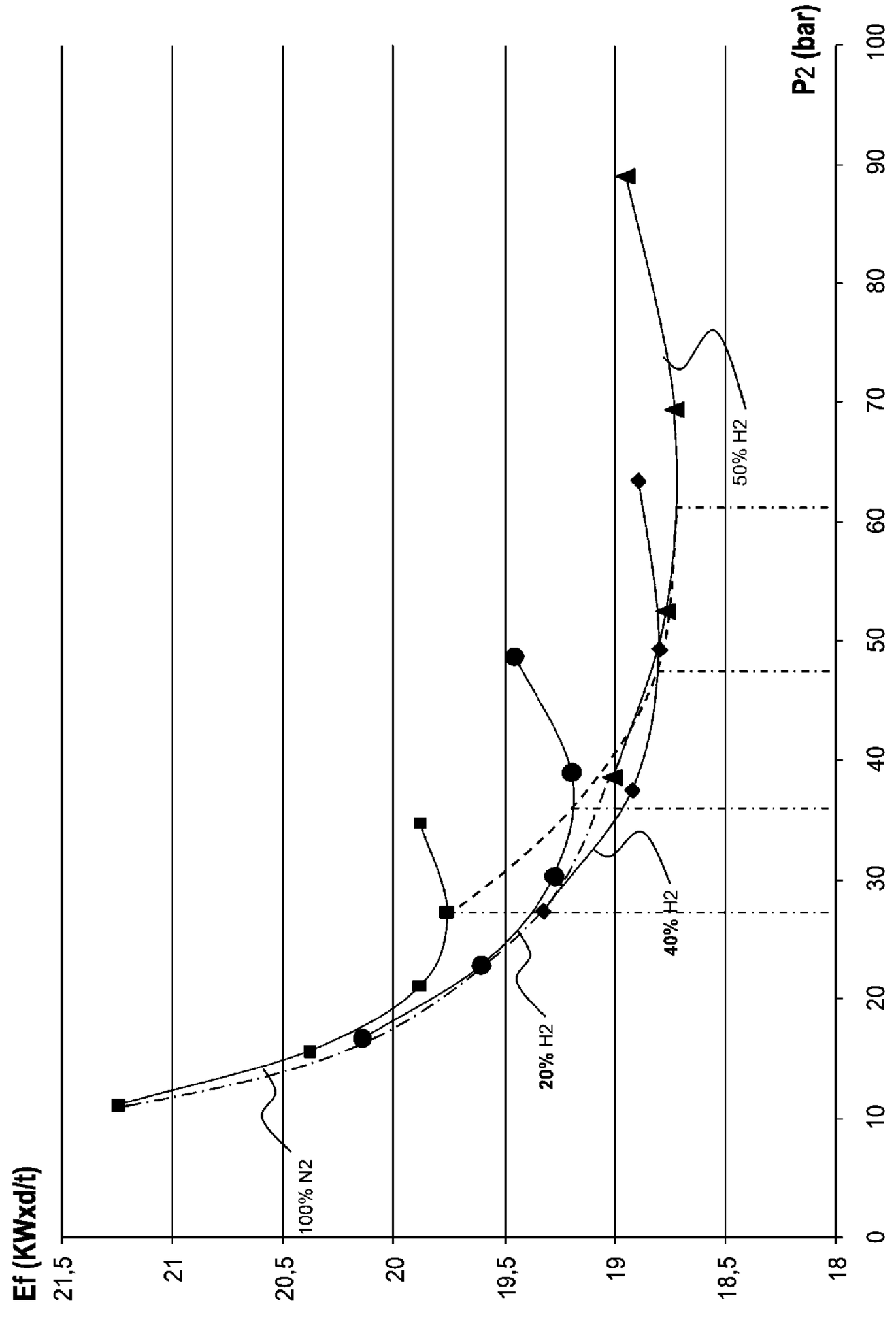
P2 (bar)
100
90
80
70
60
50
40
30
20
10
0
Ef
(KWxd/t)
21,
2
20,
2
19,
1
18,
1
100% N2
20% H2
40% H2
50% H2

FIG.6B

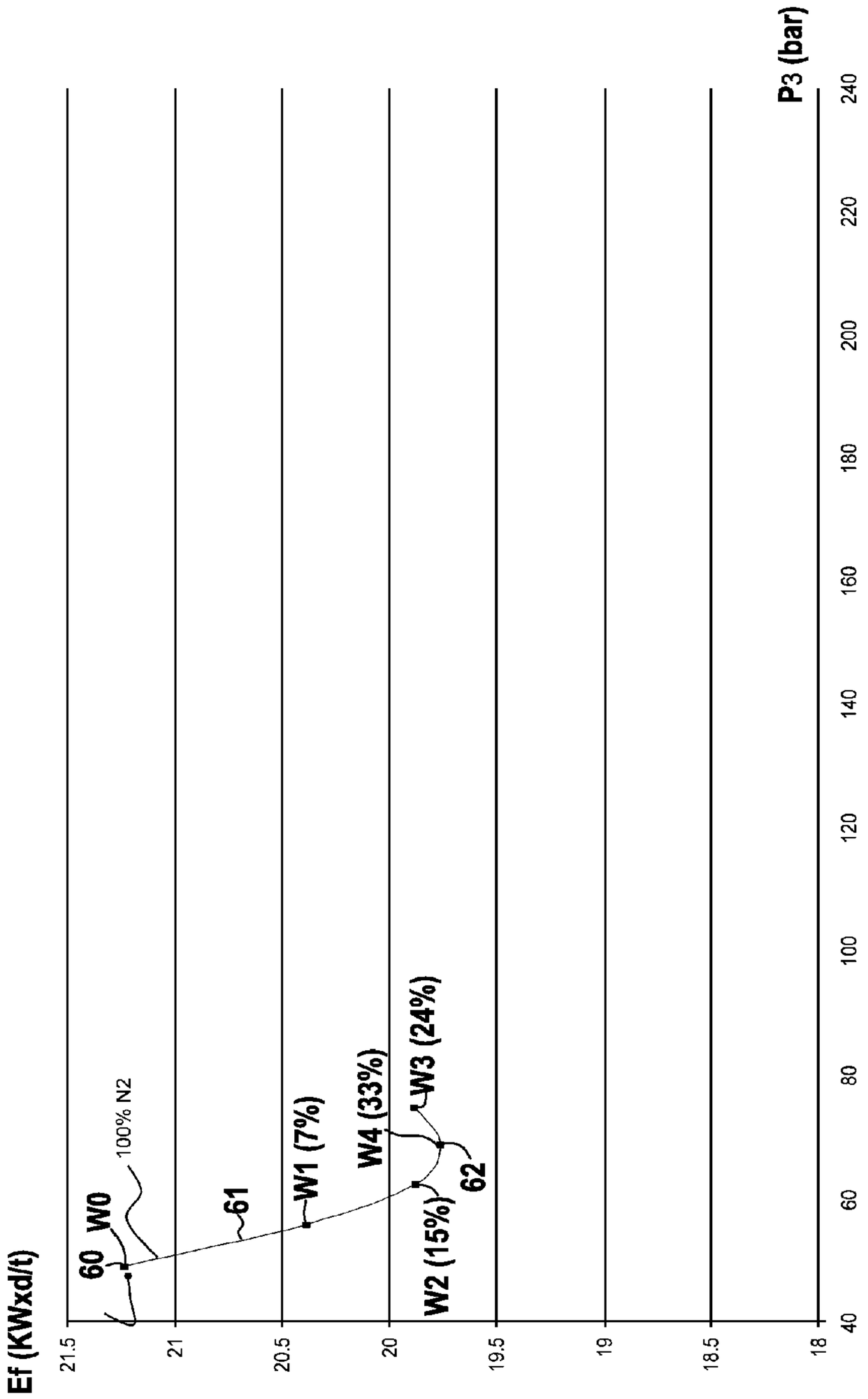
P3 (bar)
240
220
200
180
160
140
120
100
80
60
40
Efficiency (KWxd/t)
21.5
21
20.5
20
19.5
19
18.5
18
60
W0
100% N2
61
W1 (7%)
W4 (33%)
W3 (24%)
W2 (15%)
62

FIG.7

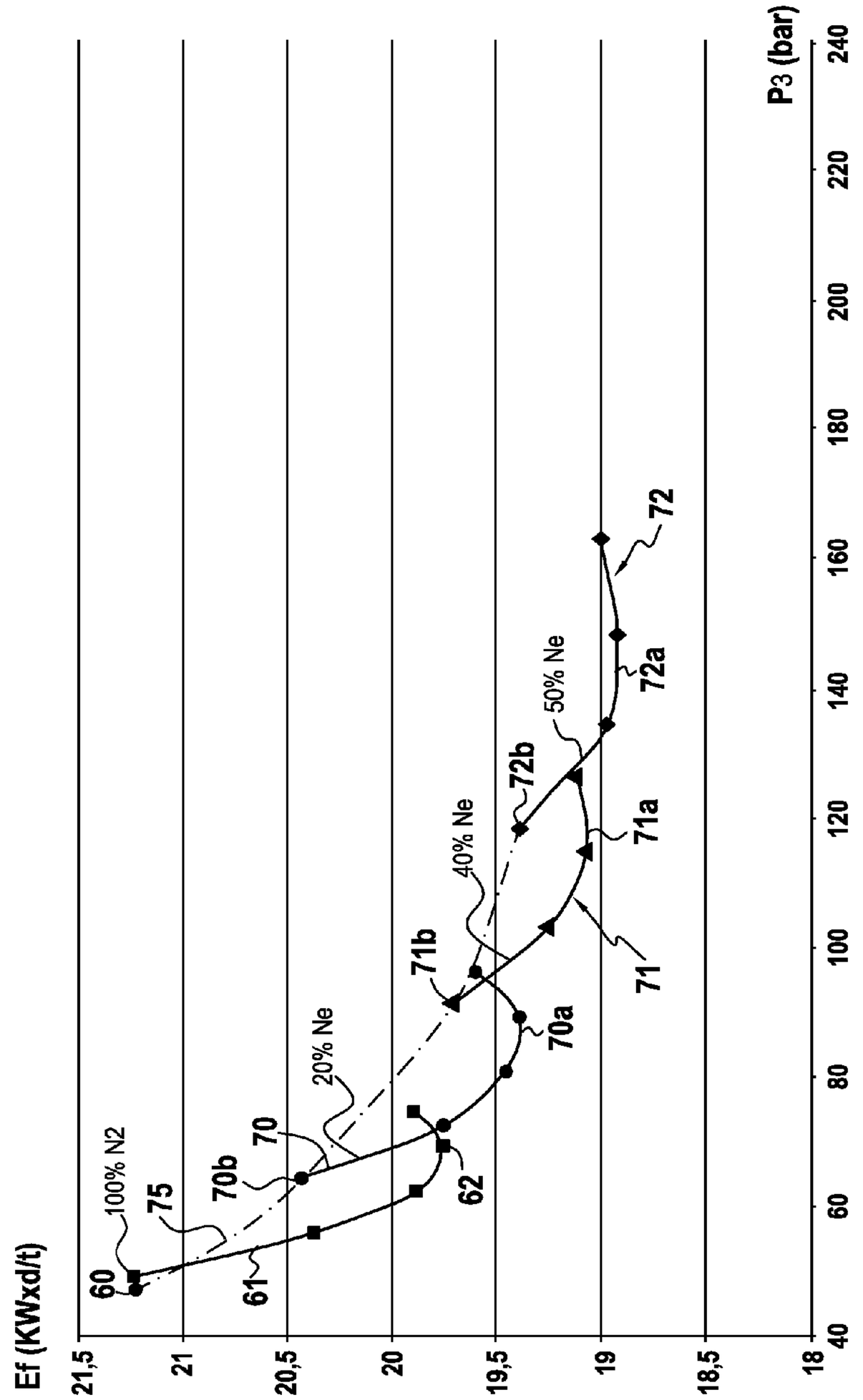
Ef (KWxd/t)
21,5
21
20,5
20
19,5
19
18,5
18
P3 (bar)
240
220
200
180
160
140
120
100
80
60
40
100% N2
20% Ne
40% Ne
50% Ne
60
61
62
70
70a
70b
71
71a
71b
72
72a
72b
75

FIG.7A

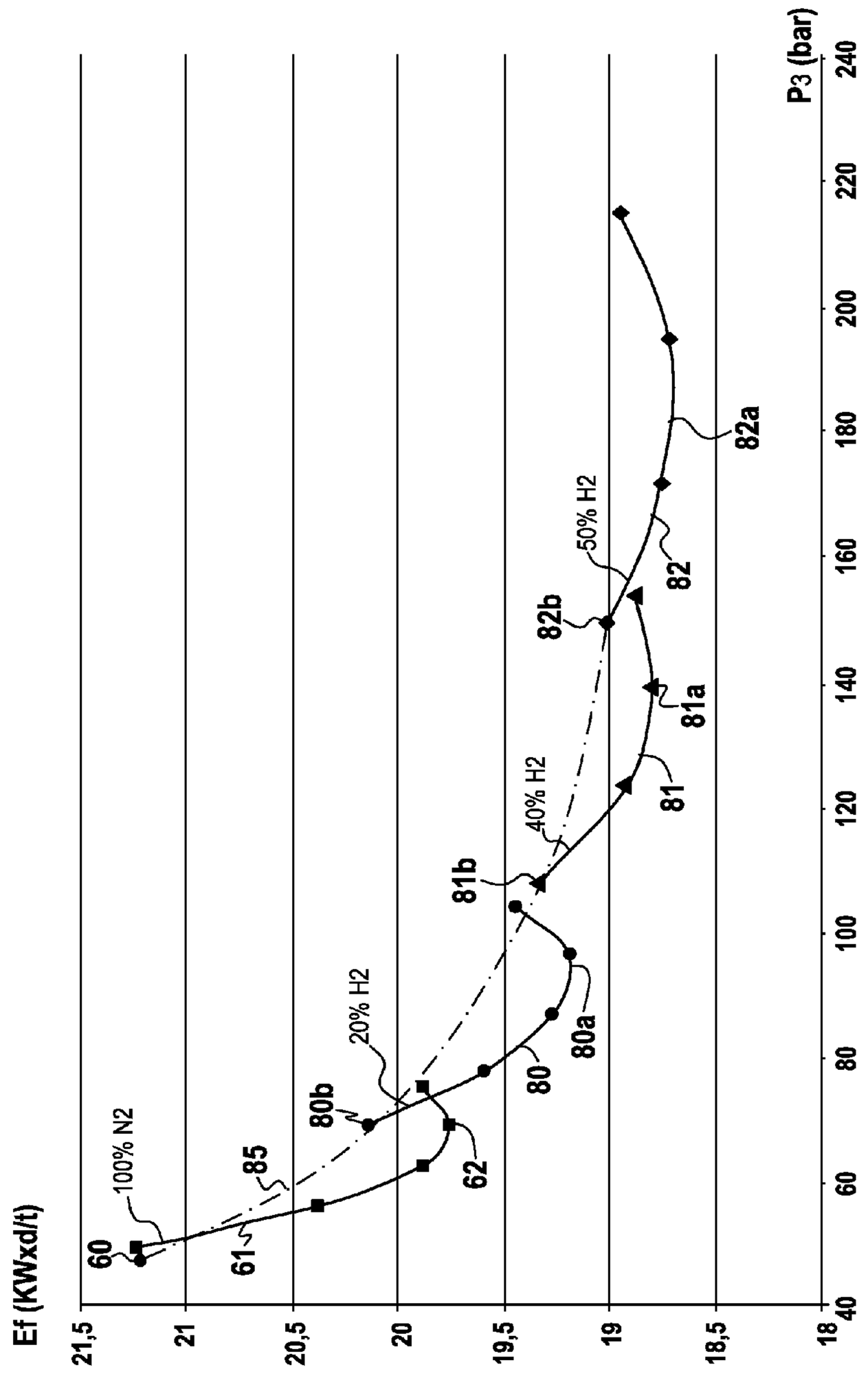
Ef (KWxd/t)
21,5
21
20,5
20
19,5
19
18,5
18
P3 (bar)
40
60
80
100
120
140
160
180
200
220
240
100% N2
20% H2
40% H2
50% H2
60
61
62
80
80a
80b
81
81a
81b
82
82a
82b
85

FIG.7B