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**Buijs et al.**(10) **Pub. No.: US 2008/0156036 A1**(43) **Pub. Date: Jul. 3, 2008**(54) **PLANT AND METHOD FOR LIQUEFYING  
NATURAL GAS**(30) **Foreign Application Priority Data**

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(2), (4) Date: **Oct. 1, 2007**(57) **ABSTRACT**

Plant and method for liquefying natural gas. The plant comprises a common pre-cooling heat exchanger train (1), two natural gas liquids extraction units (100, 100') and two main heat exchangers (200, 200') to cool the overhead light fraction from its corresponding natural gas liquids extraction unit to liquefaction.

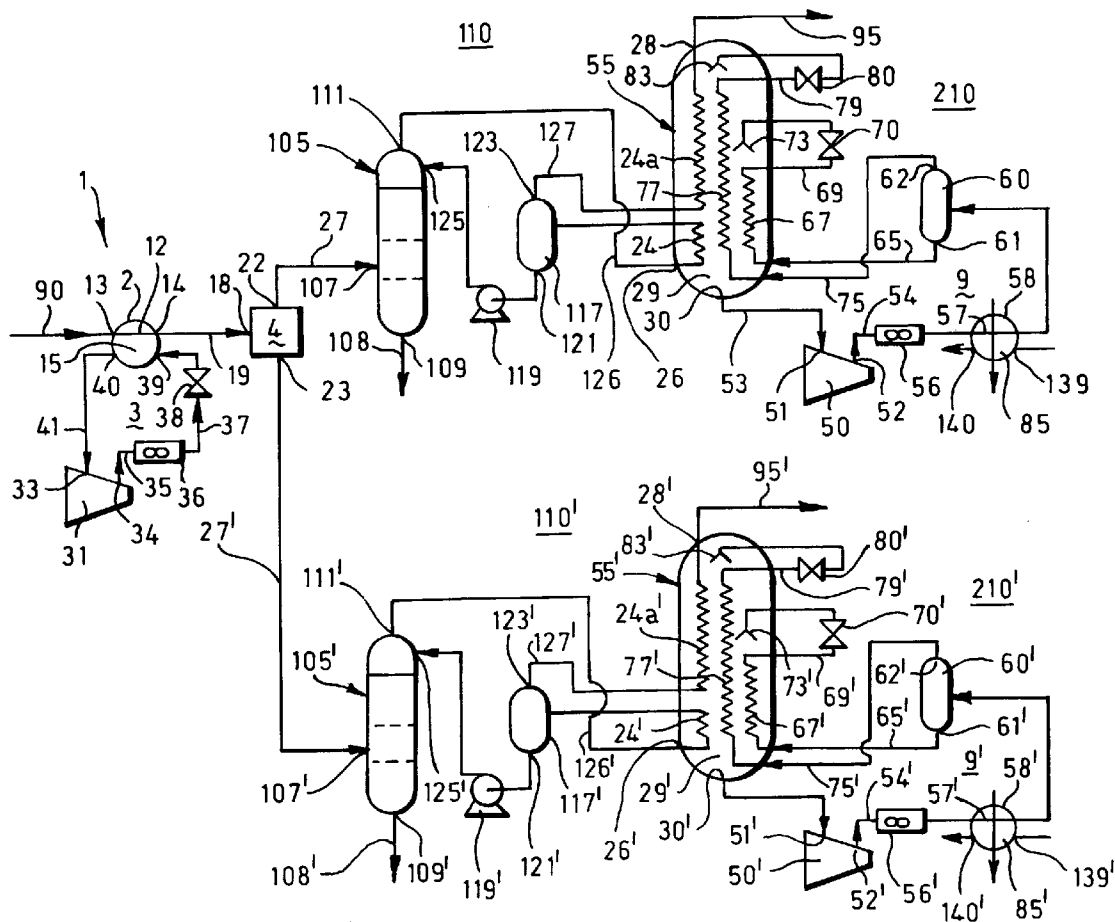


Fig.1a.

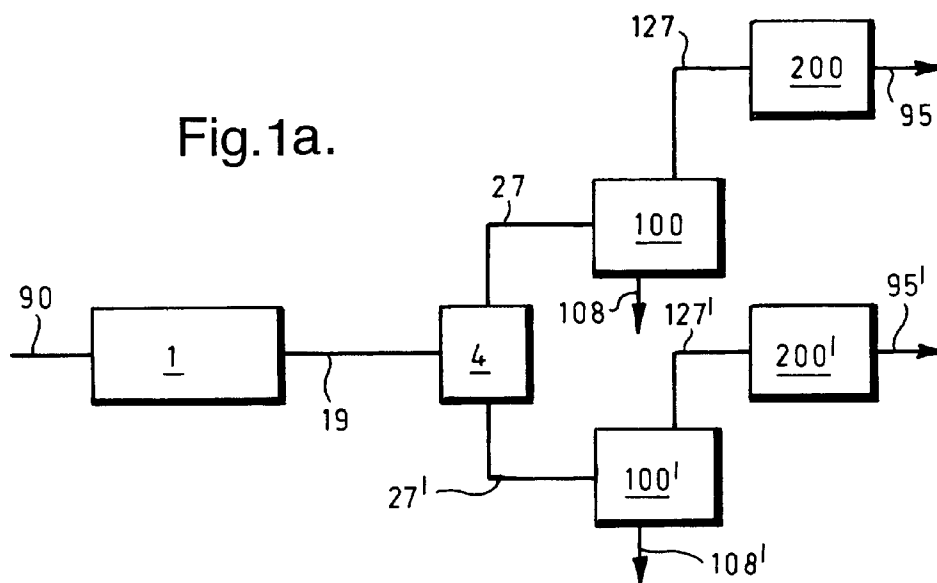


Fig.1b.

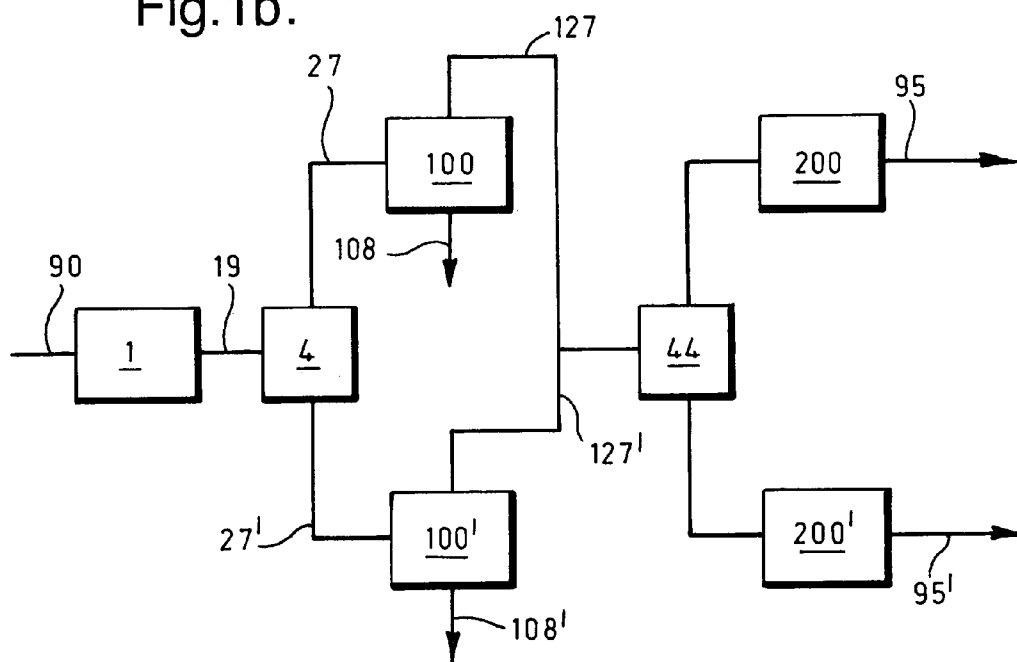


Fig.2.

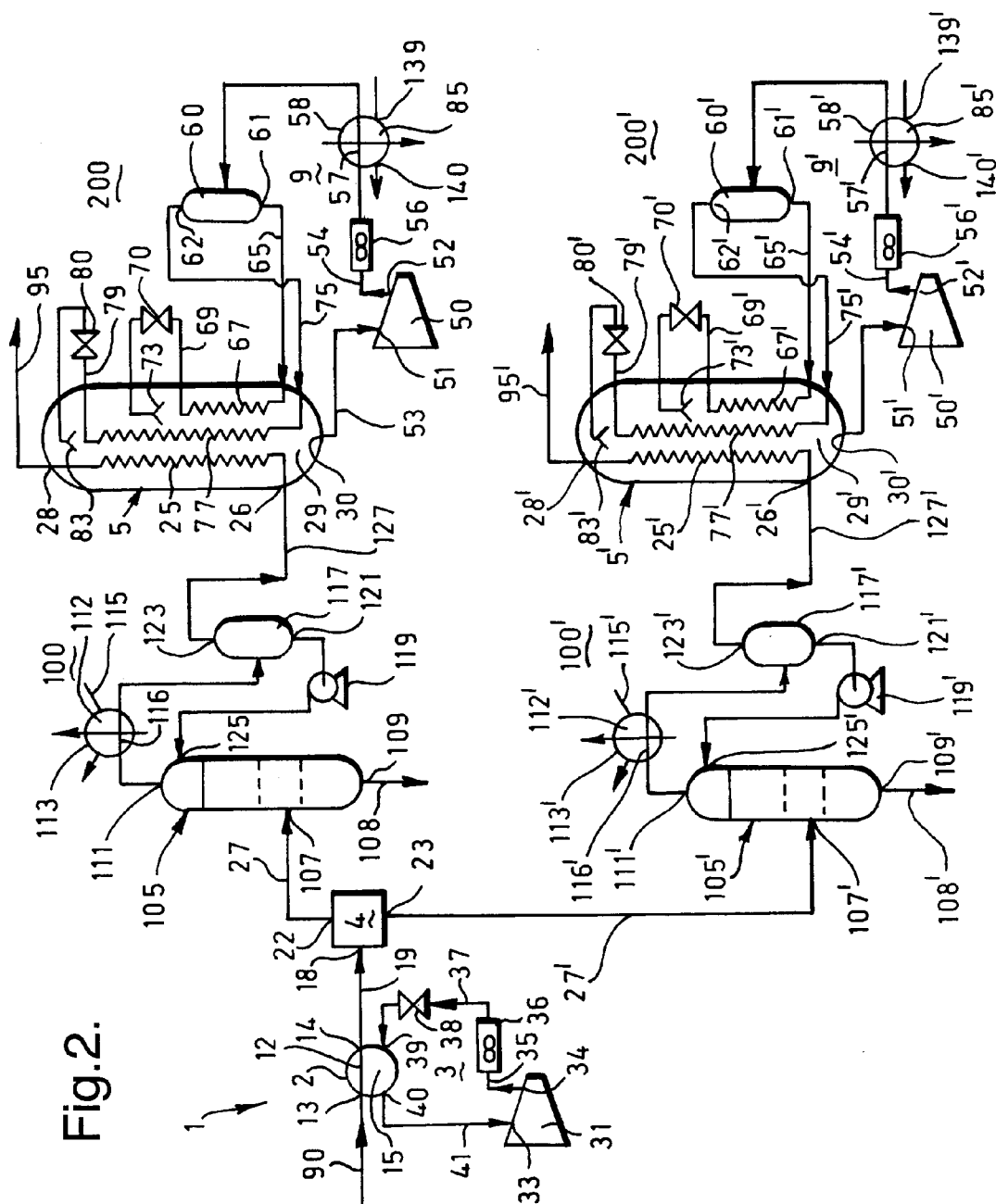


Fig. 3.

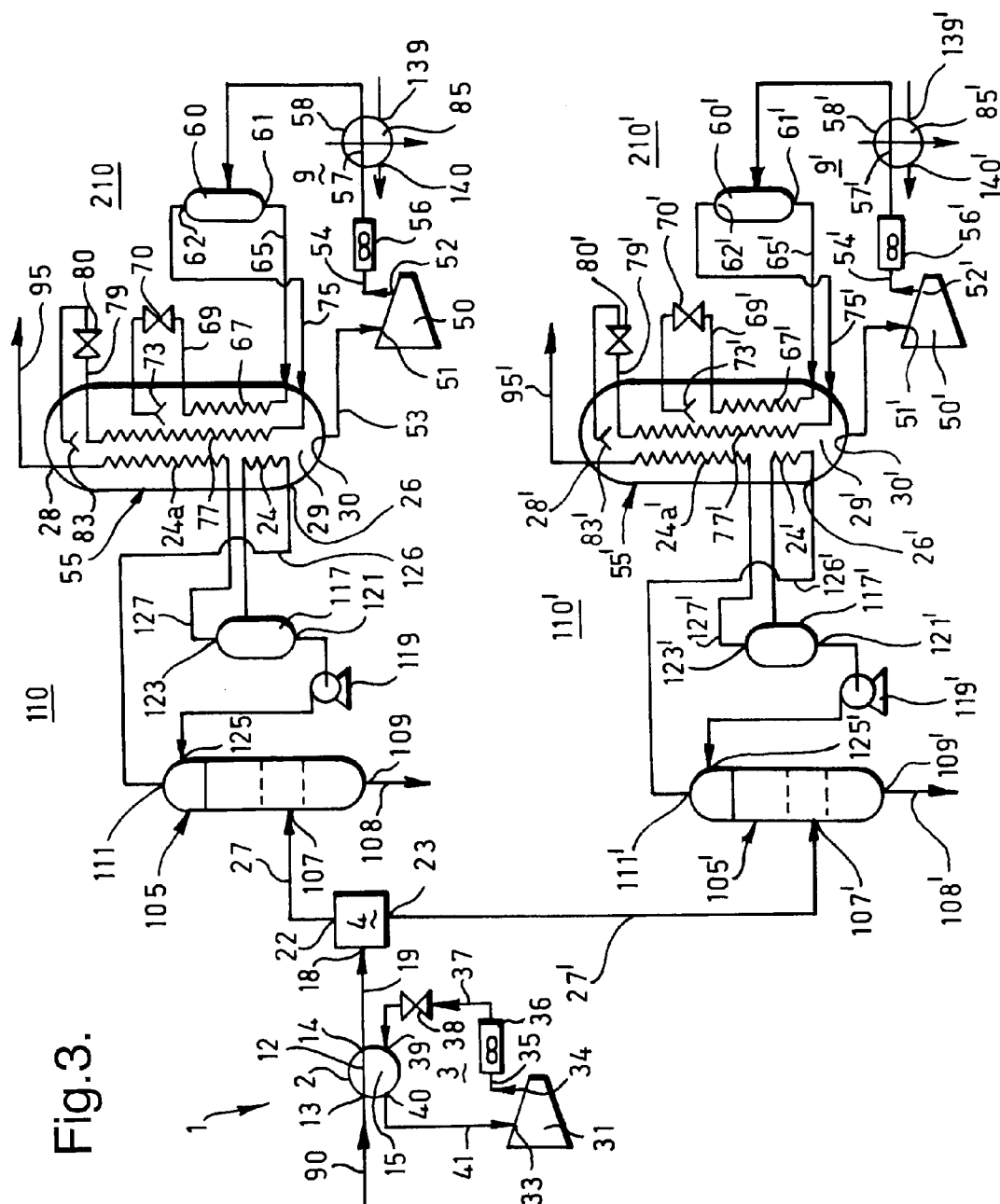
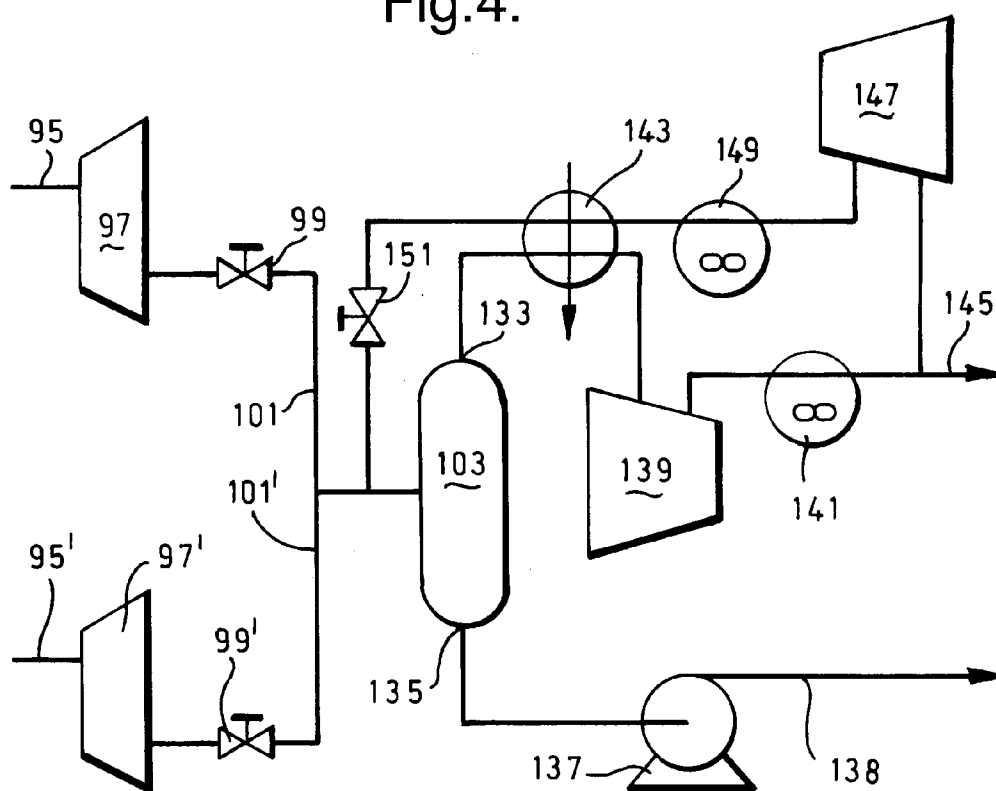


Fig.4.



## PLANT AND METHOD FOR LIQUEFYING NATURAL GAS

[0001] The present invention relates to a plant and method for liquefying natural gas.

[0002] U.S. Pat. No. 6,389,844 discloses a plant and method for liquefying natural gas. The plant according to U.S. Pat. No. 6,389,844 comprises a single common pre-cooling cycle followed by two parallel arranged main liquefaction cycles operating simultaneously, wherein natural gas flowing through the plant is liquefied and sub-cooled. As the pre-cooling cycle serves two main liquefaction cycles, the depth to which the natural gas can be pre-cooled is normally reduced.

[0003] Another plant for the production of liquefied natural gas is described in US 2005/0005635.

[0004] Different specifications of liquefied natural gas, in particular with regard to heating value, are demanded in various markets.

[0005] To meet that demand, the plant for liquefying natural gas according to the present invention comprises:

[0006] a pre-cooling heat exchanger train with one pre-cooling refrigerant circuit for removing heat from the natural gas in the pre-cooling heat exchanger train, and having an inlet for natural gas and an outlet for pre-cooled natural gas;

[0007] a distributor for splitting the natural gas stream into at least first and second natural gas substreams;

[0008] at least two natural gas liquids extraction units each provided with an extraction unit inlet arranged to receive one of the natural gas substreams, and comprising a heavy fraction outlet, and an overhead light fraction outlet; and

[0009] at least two main cryogenic systems each comprising a main heat exchanger having a first hot side having one inlet connected to the overhead light fraction outlet of at least one of the natural gas liquids extraction units and an outlet for liquefied natural gas, and each comprising a main refrigerant circuit for removing heat from the natural gas flowing through the first hot side of the corresponding main heat exchanger.

[0010] The method of liquefying a natural gas stream according to the present invention, comprises:

[0011] pre-cooling the natural gas stream in a heat exchanger train against a pre-cooling refrigerant being cycled in one pre-cooling refrigerant circuit;

[0012] splitting the natural gas stream into at least first and second natural gas substreams;

[0013] simultaneously separating each of the first and second natural gas substreams in a liquid heavy fraction, and a vaporous overhead light fraction;

[0014] further cooling the vaporous overhead light fractions into full condensation against a main refrigerant in at least two main cryogenic systems, whereby in each main cryogenic system the main refrigerant is cycled in a main refrigerant circuit; and

[0015] drawing a liquefied natural gas stream therefrom.

[0016] The pre-cooling refrigerant circuit now serves two main refrigerant circuits, but each main refrigerant circuit is served by its own natural gas liquids extraction unit. In this way the liquefaction capacity is not limited by the natural gas liquids extraction capacity.

[0017] It has been surprisingly found that natural gas liquids extraction downstream of the pre-cooling or the pre-cooling heat exchanger train is possible, whereas due to a higher flow rate of natural gas the pre-cooling temperature is

less low than in a case where the pre-cooling is followed by a single main heat exchanger with a single main refrigerant cycle.

[0018] Another advantage of the invention is that the natural gas extraction units do not have to be scaled up to accommodate the higher flow rate. It has been found that at high natural gas throughputs, the limit of feasibility of construction and transport of high-pressure separation columns is reached. This problem is circumvented by provision of two smaller columns arranged in parallel and operating simultaneously. It may even turn out envisaged that the additional capital cost (CAPEX) of providing two or more relatively small natural gas liquids extraction units in parallel is lower than that of one large natural gas liquids extraction unit accommodated to handle the full flow of natural gas.

[0019] The invention includes not only a first group of embodiments wherein each of the main heat exchangers receives the vaporous overhead light fraction exclusively from one of the natural gas liquids extraction units, but also a second group of embodiments wherein each of the main heat exchangers receives parts of the vaporous overhead light fraction from two or more natural gas liquids extraction units.

[0020] An advantage of the first group of embodiments is that the equipment line-up is relatively straight forward; an advantage of the second group of embodiments is that a possible maldistribution in the form of small variations in for instance composition or temperature of the respective vaporous overhead light fractions are wiped out.

[0021] The distributor for splitting the natural gas stream into at least first and second natural gas substreams can be located downstream of the pre-cooling heat exchanger train or upstream thereof. Herewith the splitting of the natural gas stream into first and second substreams can be done before or after pre-cooling.

[0022] Where the pre-cooling heat exchanger train comprises two or more heat exchangers arranged in series, or the pre-cooling is performed in two or more serial stages, the distributor can be located between two heat exchangers in the train to split the natural gas stream between consecutive pre-cooling stages.

[0023] An advantage of splitting the natural gas stream in two substreams upstream of a final pre-cooling stage is that the natural gas stream can be split into the first and second natural gas substreams before it is partly condensed due to the pre-cooling which reduces the likelihood of maldistribution. This advantage is also reached in a plant and method for liquefying natural gas as presently claimed but without the at least two natural gas liquids extraction units and separating each of the first and second natural gas substreams in a liquid heavy fraction.

[0024] The invention will now be described by way of example in more detail with reference to the accompanying drawings, wherein

[0025] FIG. 1a shows a general schematic flow diagram of the first group of embodiments of the invention;

[0026] FIG. 1b shows a general schematic flow diagram of the second group of embodiments of the invention;

[0027] FIG. 2 shows schematically the liquefaction plant and process according to the present invention,

[0028] FIG. 3 shows schematically a more specific embodiment of the plant and process according to the present invention; and

[0029] FIG. 4 shows schematically an end-flash unit for use in combination with the embodiments.

[0030] Reference is made to FIGS. 1*a* and 1*b*. The plant for liquefying natural gas according to the present invention comprises one natural gas pre-cooling heat exchanger train 1, a distributor 4, two main cryogenic systems 200 and 200', and two natural gas liquids extraction units 100 and 100'. The pre-cooling heat exchanger train has an inlet line 90 for natural gas and an outlet line 19 for pre-cooled natural gas. The distributor 4 is connected to the outlet line 19 and has at least two outlets 27, 27'.

[0031] Each of the natural gas liquids extraction units 100, 100' is connected to a line 27 or 27', and has a discharge line 108, 108' for discharging a heavy fraction, a discharge line 127, 127' for discharging an overhead light fraction. The heavy fraction comprises a natural gas liquid that is enriched in heavier components such as C<sub>3</sub>+ components, the overhead light fraction comprises a leaner mixture derived from these heavier components, and is to be liquefied.

[0032] Each main cryogenic system 200, 200' is associated with a discharge line 95, 95' for discharging the liquefied natural gas.

[0033] In FIG. 1*a*, a generic embodiment is shown wherein each of the main cryogenic systems 200, 200' is associated exclusively with one of the natural gas liquids extraction units 100, 100'. In FIG. 1*b*, a generic embodiment is shown wherein the product streams from the natural gas liquids extraction units 100 and 100' in respective lines 127 and 127' are brought together and redistributed in a second distribution box 44. In this embodiment, each main cryogenic system 200 and 200' thus receives parts of the vaporous overhead light fraction from both natural gas liquids extraction units 100 and 100'.

[0034] Referring now to a more detailed embodiment as shown in FIG. 2, the natural gas pre-cooling heat exchanger train 1 can comprise one pre-cooling heat exchanger 2 but suitably comprises a set of two or more heat exchangers arranged in series and/or parallel, wherein pre-cooling refrigerant is allowed to evaporate at one or more pressure levels. For simplicity, hereinafter the pre-cooling heat exchanger train 1 will be represented in the form of one pre-cooling heat exchanger 2.

[0035] The natural gas pre-cooling heat exchanger 2 has a hot side schematically shown in the form of tube 12 that has an inlet 13 for natural gas and an outlet 14 for pre-cooled natural gas. The tube 12 is arranged in the cold side 15, which can be a shell side 15, of the natural gas pre-cooling heat exchanger 2.

[0036] The plant according to the invention typically also comprises a pre-cooling refrigerant circuit 3. The pre-cooling refrigerant circuit 3 comprises a pre-cooling refrigerant compressor 31 having an inlet 33 and an outlet 34. The outlet 34 is connected by means of conduit 35 to a cooler 36, which may be an air cooler or a water cooler. Conduit 35 extends via an expansion device, here provided in the form of a throttle 38, to the inlet 39 of the cold side 15 of the natural gas pre-cooling heat exchanger 2. The outlet 40 of the cold side 15 is connected by means of return conduit 41 to the inlet 33 of the pre-cooling refrigerant compressor 31.

[0037] Suitably, the pre-cooling refrigerant circuit comprises four pressure levels for pre-cooling the natural gas stream in two or three or four stages. The pre-cooling refrigerant line-up can be provided in accordance with U.S. Pat. No. 6,637,238, which is herewith incorporated by reference.

[0038] The distributor 4 has an inlet 18 connected by means of conduit 19 to the outlet 14 for receiving pre-cooled natural gas and two outlets 22 and 23.

[0039] Alternatively, not shown here, the distributor 4 can be provided upstream of a final pre-cooling stage, whereby the two outlets 22 and 23 are connected to inlets of two parallel hot sides in the final pre-cooling stage whereby streams flowing through these parallel hot sides can heat exchange against the pre-cooling refrigerant in the pre-cooling refrigerant circuit.

[0040] Each main cryogenic system 200, 200' contains a main heat exchanger 5, 5', and a main refrigerant circuit 9, 9'. Each main heat exchanger 5, 5' comprises a first hot side 25, 25' having one inlet 26, 26'. The inlet 26 of the first hot side 25 is connected to the outlet 22 of the distributor 4 via the natural gas liquids extraction unit 100 by means of conduits 27 and 127, and the inlet 26' of the first hot side 25' is connected to the outlet 23 via the natural gas liquids extraction unit 100' by means of conduits 27' and 127'. Each first hot side 25, 25' has an outlet 28, 28' at the top of the main heat exchanger 5, 5' for liquefied natural gas. The first hot side 25, 25' is located in the cold side 29, 29' of the main heat exchanger 5, 5', which cold side 29, 29' has an outlet 30, 30'.

[0041] Main heat exchangers 5 and 5' are each associated with a liquefaction refrigerant circuit 9 respectively 9'. Each liquefaction refrigerant circuit 9, 9' comprises a liquefaction refrigerant compressor 50, 50' having an inlet 51, 51' and an outlet 52, 52'. The inlet 51, 51' is connected by means of return conduit 53, 53' to the outlet 30, 30' of the cold side 29, 29' of the main heat exchanger 5, 5'. The outlet 52, 52' is connected by means of conduit 54, 54' to a cooler 56, 56', which may be an air cooler or a water cooler, and the hot side 57, 57' of a refrigerant heat exchanger 58, 58' to a separator 60, 60'. Each separator 60 has an outlet 61, 61' for liquid at its lower end and an outlet 62, 62' for gas at its upper end.

[0042] Each refrigerant heat exchanger 58, 58' includes a cold side 85, 85' having an inlet 139, 139' and an outlet 140, 140' for allowing entry of an auxiliary refrigerant and discharge of spent auxiliary refrigerant. The cold side 85 is included in an auxiliary refrigerant cycle for which many options are feasible, amongst which are the following:

[0043] One option is that the auxiliary refrigerant cycle is embodied as a parallel cycle as disclosed in above mentioned U.S. Pat. No. 6,389,844, herewith incorporated by reference, utilizing the pre-cooling refrigerant compressor 31 and cooler 36, whereby inlet 139, 139' is connected to line 37 via an expansion device such as a throttle, and outlet 140, 140' is connected to line 41. In another option, a separate auxiliary refrigerant circuit is provided such as is disclosed in above mentioned US patent application publication 2005/0005635, herewith incorporated by reference, utilizing either one auxiliary refrigerant compressor for feeding each of refrigerant heat exchanger 58, 58' in parallel or utilizing a dedicated auxiliary refrigerant compressor for each refrigerant heat exchanger 58, 58'. In still another option, for which reference is made to FIGS. 2 and 3 of U.S. Pat. No. 6,389,844 already incorporated in the present specification, the natural gas pre-cooling heat exchanger 2 and the refrigerant heat exchangers 58 and 58' shown in FIG. 2 are combined in one integrated heat exchanger, whereby the hot sides 57 and 57' are embodied in the form of additional warm tube bundles in one or more of the pre-cooling heat exchangers 2 of the pre-cooling heat exchanger train 1.

[0044] Instead of one stage, the integrated pre-cooling heat exchanger train may comprise two or three or more stages in series, as disclosed with specific reference to FIG. 3 in U.S. Pat. No. 6,389,844 already enclosed by reference.

[0045] Each liquefaction refrigerant circuit 9, 9' further includes a first conduit 65, 65' extending from the outlet 61, 61' to the inlet of a second hot side 67, 67' that extends to a mid point of the main heat exchanger 5, 5', a conduit 69, 69', an expansion device 70, 70' and an injection nozzle 73, 73'.

[0046] Each liquefaction refrigerant circuit 9, 9' further includes a second conduit 75, 75' extending from the outlet 62, 62' to the inlet of a third hot side 77, 77' that extends to the top of the main heat exchanger 5, 5', a conduit 79, 79', an expansion device 80, 80' and an injection nozzle 83, 83'.

[0047] The two natural gas liquids extraction units 100 and 100' are each comprise a distillation column 105 respectively 105'. The distillation column 105, 105' is provided with a distillation column inlet 107, 107', that in the present embodiment is at the same time the extraction unit inlet that is connected to distributor 4. Specifically, distillation column inlet 107 is connected to outlet 22 of the distributor 4 via conduit 27, and distillation column inlet 107' is connected to outlet 23 via conduit 27'. Extraction unit outlets are provided in the form of lines 127 and 127' respectively.

[0048] The distillation column 105, 105' further has a heavy fraction outlet 109, 109' for discharging a liquid (to line 108, 108') separated from the pre-cooled natural gas stream in corresponding line 27, 27', and a light fraction overhead outlet 111, 111' for discharging a vapour separated from the pre-cooled natural gas stream in corresponding line 27, 27'.

[0049] A fractionation unit (not shown), either operating on the parallel heavy fractions or on the combined heavy fractions, can be connected to the heavy fraction outlet 109, 109'.

[0050] The distillation column 105, 105' is as shown in FIG. 2 is provided only with a rectifying section. Although not required by this invention, the distillation column can also be provided with a rectifying and a stripping section, by adding a reboiler to bring up the temperature in the bottom of the column. Also, an absorber section can be provided in the distillation column if necessary. The distillation column may be a scrub column.

[0051] The natural gas liquids extraction unit 100, 100' further comprises an overhead heat exchanger unit 113, 113', an overhead separator 117, 117' in the form of reflux drum, and a reflux pump 119, 119'. The reflux drum 117, 117' comprises a liquid reflux outlet 121, 121', and a vapour outlet 123, 123'.

[0052] The light fraction overhead outlet 111, 111' is connected to a hot side 116, 116' of the overhead heat exchanger unit 113, 113', of which the cold side 112, 112' is exposable to a cold stream 115, 115'. The hot side outlet of the overhead heat exchanger 113, 113' is connected to the reflux drum 117, 117'. The liquid reflux outlet 121, 121' is connected to a suction side of reflux pump 119, 119' of which a pressure side is connected to a reflux inlet 125, 125' provided in the corresponding distillation column 105, 105'. The vapour outlet 123, 123' is connected to line 127, 127'.

[0053] Suitably the main refrigerant circuits 9 and 9' are identical to each other and so are the main heat exchangers 5 and 5' and the natural gas liquids extraction units 100 and 100'.

[0054] During normal operation, natural gas is supplied to the pre-cooling heat exchanger train 1 via the inlet 13 of the hot side 14 of the natural gas pre-cooling heat exchanger 2 through conduit 90. Normally, depending on the natural gas composition, the natural gas is partially condensed in pre-cooling heat exchanger train 1.

[0055] Pre-cooling refrigerant is removed from the outlet 40 of the cold side 15 of the natural gas pre-cooling heat exchanger 2, compressed in the pre-cooling refrigerant compressor 31 to an elevated pressure, condensed in the condenser 36 and allowed to expand in the expansion device 38 to a low pressure. In the cold side 15 the expanded pre-cooling refrigerant is allowed to evaporate at the low pressure and in this way heat is removed from the natural gas.

[0056] Pre-cooled natural gas removed from the hot side 14 is passed to the distributor 4 through conduit 19, where it is split in into at least first and second pre-cooled natural gas substreams.

[0057] The amounts of natural gas passing through conduits 27 and 27' are suitably equal to each other. Through conduits 27 and 27' the respective first and second pre-cooled natural gas streams is supplied to the inlets 107 and 107' of the natural gas liquids extraction units 100 and 100'. Here, each of the first and second pre-cooled natural gas substreams are fed into their respective distillation columns 105 and 105' where they are simultaneously separated, typically by distillation or scrubbing, in a heavy fraction comprising the condensed part of the corresponding substream, and a vaporous overhead light fraction.

[0058] Depending on the temperature in the distillation column, the vaporous overhead light fraction is derived from C<sub>3</sub>+ components including propane and contains predominantly methane, and often also C<sub>2</sub> components including ethane, and nitrogen.

[0059] The vaporous light overhead stream leaves the distillation column 105, 105' via light fraction overhead outlet 111, 111' after which it is fed into the hot side 116, 116' of overhead heat exchanger 113, 113' where it is partially condensed into a partially condensed overhead stream comprising a mixture of light condensate and light vapour.

[0060] The partially condensed overhead stream is fed to the reflux drum 117, 117' where the light condensate is separated from the light vapour. The light condensate is drawn from the reflux drum 117, 117' via liquid reflux outlet 121, 121', and fed a cold liquid reflux into the distillation column 105, 105'.

[0061] The light vapour is drawn from the vapour outlet 123, 123' and fed to the inlets 26 and 26' of the first hot sides 25 and 25' of the main heat exchangers 5 and 5'. In the first hot side 25, 25' the light vapour fraction from the natural gas is liquefied and sub-cooled. Sub-cooled natural gas is removed through conduits 95 and 95'. The sub-cooled natural gas is passed to a unit for further treating, of which some options will be discussed later in this specification, and to tanks for storing the liquefied natural gas (not shown).

[0062] Main refrigerant is removed from the outlet 30, 30' of the cold side 29, 29' of the main heat exchanger 5, 5', compressed to an elevated pressure in the liquefaction refrigerant compressor 50, 50'. The heat of compression is removed in cooler 56, 56' and further heat is removed from the main refrigerant in the refrigerant heat exchanger 58, 58' to obtain partly condensed refrigerant. Partly condensed main refrigerant is then separated in separator 60, 60' into a heavy, liquid fraction and a light, gaseous fraction, which fractions are further cooled in the second and the third hot side 67, 67' and 77, 77' respectively to obtain liquefied and sub-cooled fractions at elevated pressure. The sub-cooled refrigerants are then allowed to expand in expansion devices 70, 70' and 80, 80' to a lower pressure. At this pressure the refrigerant is allowed to evaporate in the cold side 29, 29' of the main heat

exchanger 5, 5' to remove heat from the natural gas passing through the first cold side 25, 25'.

[0063] The cold stream 115, 115', or overhead refrigerant stream 115, 115', required to condense the liquid reflux out of the vaporous overhead light fraction can come from any suitable source. For instance, it can be fed with a slip stream from cycle 3, or it can be integrated as one pressure level in cycle 3. In the latter case the hot side 116, 116' can be integrated parallel to the hot side 12 into an integrated heat exchanger, or the hot side 116, 116' can be part of a separate heat exchanger unit 113, 113' whereby the pre-cooling refrigerant is fed into the cold side 112, 112'.

[0064] Alternatively, the overhead refrigerant stream 115, 115' can be fed with a slip stream of the main refrigerant, for instance from line 65, 65'. This can be achieved in an arrangement wherein the cold side 115, 115' of the overhead heat exchanger is in fluid communication with at least one of the at least two main refrigerant circuits 9, 9'. An advantage of indirect heat exchanging the vaporous overhead light fraction with the main refrigerant in at least one of the at least two main refrigerant circuits 9, 9' is that the temperature of the pre-cooled natural gas stream is as low as possible which helps in achieving a deeper C<sub>3</sub>+ extraction in the natural gas liquids separation. In addition, the temperature of the liquid reflux stream leaving outlet 121, 121' can be lower to increase the C<sub>3</sub>+ recovery.

[0065] Other options are formed by any combination of two or more of the described options for cooling the vaporous overhead light fraction, in particular a combination involving an integration of the hot side 116, 116' in another heat exchanger followed by a separate overhead heat exchanger unit 113, 113' arranged downstream of the integrated one.

[0066] It has been found that the temperature of the pre-cooled natural gas lies around -25° C. when the compressor driver power for each of the main refrigerant circuits 9, 9' and the compressor driver power for the pre-cooling refrigerant circuit 3 are equal and the plant is operated at full capacity. The pressure of the pre-cooled natural gas is typically between 40 and 60 bar. Preferably the temperature of the liquid reflux stream lies between -25° C. and -65° C., whereby the lower the temperature the more C<sub>3</sub>+ components are separated out of the pre-cooled natural gas. More preferably, the temperature of the liquid reflux stream is lower than -31° C. A 40 to 45% propane recovery is feasible with a cold reflux temperature of about -45° C., using main refrigerant for the overhead cooling in overhead heat exchanger 113, 113'. This depends on pressure and composition of the gas.

[0067] Reference is now made to FIG. 3 which shows an embodiment involving one specific example of utilizing main refrigerant from one of the main refrigerant circuits 9, 9' for cooling vaporous overhead light fraction drawn from the overhead separator 117, 117'. The hot side 116, 116' is integrated into the main heat exchanger. FIG. 3 largely corresponds to FIG. 2 but wherein natural gas liquids extraction units 100, 100' have been replaced by an alternative embodiment of natural gas liquids extraction unit 110, 110'. Insofar as FIG. 3 corresponds to FIG. 2 it will not be described again, but general reference is instead made to corresponding parts of FIG. 2.

[0068] The main cryogenic heat exchangers 5, 5' have been replaced by a modified version 55, 55', wherein the hot side 25, 25' is divided in an upstream part 24, 24' and a downstream part 24a, 24a'.

[0069] In the alternative embodiment, the light fraction overhead outlet 111, 111' is connected to inlet 26, 26' of the corresponding upstream part 24, 24' via conduit 126, 126'. The outlet of the upstream part 24, 24' is connected to the reflux drum 117, 117' and the vapour outlet 123, 123' of the reflux drum 117, 117' is connected to the corresponding inlet of the downstream part 24a, 24a' of the hot side 25, 25' via conduit 127, 127'. As with main heat exchanger 5, 5', the downstream part 24a, 24a' has an outlet 28, 28' at the top of the main heat exchanger 55, 55' for liquefied natural gas.

[0070] During normal operation of the alternative embodiment, the cold required for condensing the liquid reflux out of the vaporous overhead light fraction is provided by the main refrigerant.

[0071] In another embodiment (not shown) the natural gas liquids extraction unit 100, 100' and/or 110, 110' and the separating of the partially condensed natural gas substreams in a heavy fraction comprising the condensed part of the corresponding substream, and a vaporous overhead light fraction, takes a form in accordance with embodiments thereof as disclosed in International publication WO 2004/069384, herewith incorporated by reference. In particular, the cold liquid reflux in such embodiments is split into first and second reflux streams of which the first is introduced in the top of the scrub column and the second in a mid point.

[0072] In the above-described embodiments, the pre-cooling refrigerant is suitably a single component refrigerant, such as propane, or a mixture of hydrocarbon components or another suitable refrigerant used in a compression cooling cycle or in an absorption cooling cycle. The main refrigerant is suitably a multi-component refrigerant comprising nitrogen, methane, ethane, propane and butane.

[0073] Suitably, the refrigerant heat exchangers 58 and 58' comprise a set of two or more heat exchangers arranged in series, wherein the pre-cooling refrigerant is allowed to evaporate at one or more pressure levels.

[0074] The main heat exchangers 5 and 5' and 55 and 55' can be of any suitable design, such as a spool-wound heat exchanger or a plate-fin heat exchanger.

[0075] In the embodiments as described with reference to FIGS. 2 and 3, the main heat exchangers 5, 5', 55, 55' has a second and a third hot side, 67, 67' and 77, 77', respectively. In an alternative embodiment, the main heat exchanger has only one hot side in which the second and the third hot side are combined. In this case the partly condensed main refrigerant is directly supplied to the third hot side 77, 77', without separating it into a heavy, liquid fraction and a light, gaseous fraction.

[0076] The compressors 31, 50 and 50' can be multi-stage compressors with inter-cooling, or a combination of compressors in series with inter-cooling in between two compressors, or a combination of compressors in parallel.

[0077] The compressors 31, 50 and 50' in the pre-cooling refrigerant circuit 3 and the two main refrigerant circuits 9 and 9' can be turbine driven or electric motor driven, or combined turbine/electric motor driven.

[0078] Suitably the turbine (not shown) in the pre-cooling refrigerant circuit is a steam turbine. In this case suitably, the steam required to drive the steam turbine is generated with heat released from cooling the exhaust of the gas turbines (not shown) of the main refrigerant circuits.

[0079] The present invention provides an expandable plant for liquefying natural gas, wherein in a first stage a single train is built with a 100% liquefaction capacity, and wherein in a

second stage the second main heat exchanger and the second liquefaction refrigerant circuit of the same size as the first ones can be added to expand the liquefaction capacity to between about 140 and about 160%, while the  $C_3+$  components from the natural gas can be controlled.

**[0080]** An advantage of the present invention is that the conditions of pre-cooling and liquefaction, for example the compositions of the refrigerant, can easily be adapted such that an efficient operation is achieved. Moreover, in case one of the liquefaction circuits has to be taken out of operation, the conditions can be adapted to work efficiently with a single liquefaction train.

**[0081]** Calculations have furthermore shown that the liquefaction efficiency (amount of liquefied gas produced per unit of work done by the compressors) is not adversely affected by using a pre-cooling refrigerant circuit serving two main refrigerant circuits.

**[0082]** The liquefaction capacity can be expanded even more by provision of at least one end-flash unit, connected to the outlet conduits **95**, **95'** for liquefied natural gas. FIG. 4 shows an embodiment of such an end flash unit that can be added to any one of the plants described above. Each conduit **95**, **95'** is connected to an end flash expander **97**, **97'** and a throttle **99**, **99'**. The low pressure ends discharge into conduits **101**, **101'** which both connect to an end flash gas separator **103**.

**[0083]** Alternatively, the junction where liquefied natural gas in conduits **95** and **95'** is combined upstream a single end flash expander (not shown).

**[0084]** The end flash gas separator is provided with an end flash gas outlet **133** and a liquefied natural gas outlet **135**. An optional pump **137** may be provided to bring the liquefied natural gas to any desired pressure before discharging it in line **138** for transport or storage.

**[0085]** The flash gas outlet **133** is connected to a compressor **139**. The high-pressure outlet of the compressor **139** is connected to a cooler **141**, which can be an ambient cooler. Upstream of the compressor **139** a heat exchanger **143** is provided to be able to retain the cold vested in the end flash gas.

**[0086]** During normal operation, the pressure in the liquefied natural gas is lowered in the end flash expander **97**, **97'** and the throttle **99**, **99'**, preferably to atmospheric or near atmospheric conditions. This expansion lowers the temperature of the liquefied natural gas, and also end flash gas is formed in the process.

**[0087]** Typically the temperature is lowered by approximately 10° C. when flashed down from 50 bar to atmospheric pressure. Because of the additional lowering of the temperature, more liquified natural gas can be produced with a certain cooling power in the pre-cooling train **1** and the main cryogenic systems **200**, **200'**.

**[0088]** The end flash gas is separated from the liquefied natural gas in the end flash gas separator **103**.

**[0089]** The end flash gas leaving the end flash gas separator **103** is compressed to a pressure whereby it can be discharged via line **145** for further use, for instance as fuel gas. The cold present in the end flash gas can be retained via heat exchanger **143**, for instance to pre-cool the main refrigerant. In that case, the heat exchanger **143** could be included in the main refrigerant circuits **9**, **9'**.

**[0090]** In order to even further expand the capacity of the plant, an optional end flash gas feedback loop can be provided whereby a part of the end flash gas in line **145** is at least partly condensed and re-injected into the liquefied natural gas

upstream of the end flash separator **103**. To this end, the optional feedback loop can comprise a further compressor **147**, of which the low pressure end is connected to line **145**. The high-pressure end of the further compressor **147** is connected to a line upstream of the end flash gas separator, via consecutively an optional further cooler **149**, a heat exchanger **143** and an expansion device such as a throttle **151**.

**[0091]** With the optional reinjection, the further compressors **139** and **147** provide extra points where cooling duty can be put into the process and the cooling temperature in the main refrigerant circuits can be increased. Because of the extra cooling duty added in this way a higher amount of liquid natural gas can be produced. Calculations have revealed that a 4 to 5% additional liquefaction capacity can be achieved with the end flash system including the optional recycling.

**[0092]** Other end flash systems or extended can be used instead of those described here. Included by reference is the end flash system as disclosed in U.S. Pat. No. 5,893,274.

**1.** A plant for liquefying natural gas comprising:

- a pre-cooling heat exchanger train with one pre-cooling refrigerant circuit for removing heat from the natural gas in the pre-cooling heat exchanger train, and having an inlet for natural gas and an outlet for pre-cooled natural gas;
- a distributor for splitting the pre-cooled natural gas stream into at least first and second natural gas substreams;
- at least two natural gas liquids extraction units each provided with an extraction unit inlet arranged to receive one of the natural gas substreams, and comprising a heavy fraction outlet, and an overhead light fraction outlet; and
- at least two main cryogenic systems each comprising a main heat exchanger having a first hot side having one inlet connected to the overhead light fraction outlet of at least one of the natural gas liquids extraction units and an outlet for liquefied natural gas, and each comprising a main refrigerant circuit for removing heat from the natural gas flowing through the first hot side of the corresponding main heat exchanger.

**2.** The plant of claim **1**, wherein each of the natural gas liquids extraction units is provided with a reflux inlet arranged to receive a liquid reflux from a liquid reflux outlet of an overhead separator, which overhead separator is provided with an inlet in fluid communication with the overhead light fraction outlet and a vapour outlet in fluid communication with the corresponding main cryogenic heat exchanger.

**3.** The plant of claim **2**, wherein upstream of the overhead separator an overhead heat exchanger is provided for removing heat from the overhead light fraction, of which overhead heat exchanger the cold side is in fluid communication with at least one of the at least two main refrigerant circuits.

**4.** The plant of claim **1**, further comprising at least one end flash unit, connected to the outlets for liquefied natural gas of the at least two heat exchangers and comprising at least an outlet for end flash gas and an outlet for liquefied natural gas.

**5.** The plant of claim **1**, wherein the distributor has two outlets, and wherein the plant comprises two natural gas liquids extraction units and two main heat exchangers.

**6.** A method of liquefying a natural gas stream, comprising: pre-cooling the natural gas stream in a heat exchanger train against a pre-cooling refrigerant being cycled in one pre-cooling refrigerant circuit, thereby obtaining a pre-cooled natural gas stream;

splitting the pre-cooled natural gas stream into at least first and second natural gas substreams;  
simultaneously separating each of the first and second natural gas substreams in a liquid heavy fraction, and a vaporous overhead light fraction;  
further cooling the vaporous overhead light fractions into full condensation against a main refrigerant in at least two main cryogenic systems, whereby in each main cryogenic system the main refrigerant is cycled in a main refrigerant circuit; and  
drawing a liquefied natural gas stream therefrom.

7. The method of claim 6, wherein further cooling comprises partially condensing each of the vaporous overhead light fractions to form light condensate and light vapour, separating the light condensate from the light vapour, feeding the light condensate as a cold reflux into the step of simultaneously separating each of the first and second partially condensed natural gas substreams and further cooling the light vapour into full condensation.

8. The method of claim 7, wherein the partially condensing each of the vaporous overhead light fractions comprises indirect heat exchanging with the main refrigerant in at least one of the at least two main refrigerant circuits.

9. The method of claim 6, wherein the liquefied natural gas stream is subsequently expanded whereby a mixture is formed comprising an even further cooled liquefied natural gas and a flash vapour, whereby the flash vapour is separated from the even further cooled liquefied natural gas, compressed, at least partly condensed and reinjected in the liquefied natural gas stream upstream of the separating the flash vapour.

10. The plant of claim 2, further comprising at least one end flash unit, connected to the outlets for liquefied natural gas of

the at least two heat exchangers and comprising at least an outlet for end flash gas and an outlet for liquefied natural gas.

11. The plant of claim 3, further comprising at least one end flash unit, connected to the outlets for liquefied natural gas of the at least two heat exchangers and comprising at least an outlet for end flash gas and an outlet for liquefied natural gas.

12. The plant of claim 2, wherein the distributor has two outlets, and wherein the plant comprises two natural gas liquids extraction units and two main heat exchangers.

13. The plant of claim 3, wherein the distributor has two outlets, and wherein the plant comprises two natural gas liquids extraction units and two main heat exchangers.

14. The plant of claim 4, wherein the distributor has two outlets, and wherein the plant comprises two natural gas liquids extraction units and two main heat exchangers.

15. The method of claim 7, wherein the liquefied natural gas stream is subsequently expanded whereby a mixture is formed comprising an even further cooled liquefied natural gas and a flash vapour, whereby the flash vapour is separated from the even further cooled liquefied natural gas, compressed, at least partly condensed and reinjected in the liquefied natural gas stream upstream of the separating the flash vapour.

16. The method of claim 8, wherein the liquefied natural gas stream is subsequently expanded whereby a mixture is formed comprising an even further cooled liquefied natural gas and a flash vapour, whereby the flash vapour is separated from the even further cooled liquefied natural gas, compressed, at least partly condensed and reinjected in the liquefied natural gas stream upstream of the separating the flash vapour.

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