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(54) Title: A METHOD FOR LIQUEFACTION OF A PRE-PROCESSED NATURAL GAS

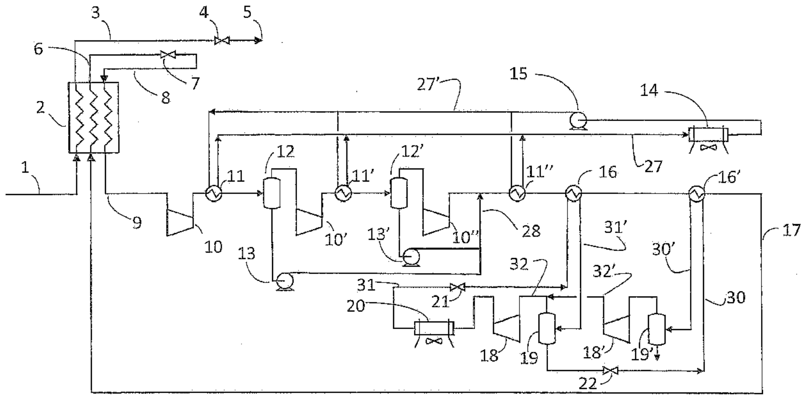

Fig. 4

(57) Abstract: A method for liquefaction of a pre-processed natural gas to produce LNG, where pre-processed natural gas is introduced into a LNG heat exchanger where the pre-processed natural gas is liquefied by cooling against an evaporating primary refrigerant, where evaporated primary refrigerant is withdrawn from the LNG heat exchanger and re-liquefied by compression in a series of compressor steps, where the compressed gas from each compression step is cooled by means of heat exchangers, wherein an aqueous cooling medium cooled in an array of air coolers, is used for cooling of the primary refrigerant, is described.

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A method for liquefaction of a pre-processed natural gas

Description

Technical Field

[0001] The present invention relates to improvements in methods and plants for liquefaction of natural gas to provide Liquefied Natural Gas (LNG) with improved economics and a reduction of the environmental impact including the elimination of the water intake of today's floating liquefaction plants. More specifically, the present invention relates to a method and plant for LNG production environmentally suited to locations offshore, or for locations near coastlines, with increased safety and liquefaction efficiency.

Background Art

[0002] Natural gas is becoming more important as the world's energy demand increases as well as its concerns about air and water emissions increase. Natural gas is readily available, in particular with the new technologies to utilize shale gas. It is much cleaner-burning than oil and coal, and does not have the hazard or waste deposition problems associated with nuclear power. The emission of greenhouse gases is lower than for oil, and only about one third of such emissions from coal.

[0003] There is substantial international trade in natural gas. However, its price differs significantly in different parts of the world. A large fraction of this trade is in the form of liquefied natural gas (LNG). LNG is produced using two major processing steps. The first step is gas pre-treatment to remove components that can solidify when cooled to cryogenic temperatures, mainly sour components and water. Trace elements, mainly mercury which can form amalgams -- in particular with aluminum process components -- are also removed from the gas. Heavy hydrocarbon fractions or Natural Gas Liquids (NGL) may be removed from the gas in the first or second of the two LNG processing steps. The second processing step is mainly liquefaction of the purified gas, which then comprises mainly methane. This methane, with small amounts of heavier components, is liquid at atmospheric pressure and about - 163°C. The LNG is shipped to the destination and re-gasified.

[0004] Processing of natural gas to produce LNG has traditionally been done in large land based facilities which include the two steps of pre-treatment and liquefaction in the same location. Recent developments in technology and markets have enabled construction of LNG plants on floating structures, a development that has inspired movement of a substantial portion of LNG processing facilities offshore to Floating Liquefied Natural Gas facilities (FLNG) to exploit large offshore gas reservoirs. The FLNGs are typically designed to be located at a distance from a coast and are connected to natural gas reservoirs through sub-sea systems. The FLNGs typically are also designed to serve as buffer storage and as terminals for loading of LNG tankers that are used for transport of the LNG to the markets.

[0005] The recent development towards FLNGs has made offshore natural gas resources more available to the market relative to piping the gas to shore for liquefaction, and has resulted in a reduction of capital cost for establishing a LNG plant. Other key drivers include reduction of onshore environmental impacts; reduction of land use issues for equipment and infrastructure; and reduced likelihood of opposition from local communities. The entire FLNG plant can be built in a shipyard, which is efficient and improves quality control, cost control and reduces construction time. FLNG’s are also mobile and can be transferred to alternative locations if required.

[0006] Numerous studies of FLNG technologies have been carried out over the last couple of decades. Currently, several projects are underway worldwide. Actual construction has started for three units only, the Shell Prelude project, the Exmar /Pacific Rubicales barge project, and the Petronas FLNG 1 project.

[0007] In these and other projects, both gas pre-processing and liquefaction will typically be located on the deck of the FLNG. Space below deck is used for LNG storage and marine-specific equipment. The area available on the FLNG deck is generally only about 20% of the area used for similar facilities onshore. This reduced process lay-out space presents safety issues, including proximity to living quarters and limited space for safety barriers. Significantly, it also limits the size of the processing plants and the possibilities to utilize economies of scale.

[0008] In addition to safety issues, the liquefaction process involves environmental issues. The liquefaction process generates large amounts of heat which must be transferred to the environment. Large amounts of sea water are needed for cooling purposes onboard the FLNG, water that is subsequently being discharged at a higher temperature. The mechanical stress in sea water pipes, pumps and fittings and the increased water temperature are harmful to marine life. Additionally, the use of toxic chemicals to prevent fouling leading the decreased cooling efficiency and finally clogging, is detrimental to marine life and will probably be prohibited in many coastal waters, such as in the state of Louisiana in the near future. Submerged cooling coils are not preferred as the performance of cooling coils is difficult, if even impossible to predict, due to varying operating conditions as a result of variation in current, seawater temperature and fouling .

[0009] A novel adaptation of FLNG is the Coastal Liquefaction, Storage and Offloading (CLSO) facility. The CLSO adaptation addresses FLNG safety, environmental impact and processing capacity issues. The first processing step, gas pre-processing, is mainly performed on shore, on separate terminals or on dedicated floating systems, instead of occupying valuable space on the FLNG. This includes extraction of heavy hydrocarbons, NGLs, from the gas. Contrary to some known systems specifically extracting NGLs at the same location of the liquefaction plant, utilizing low temperatures in the liquefaction plant for this purpose, such as described e.g. in WO9801335, in the name of Den norske stats Oljeselskap AS (now Statoil ASA), there is typically no extraction of NGLs on a CLSO.

[0010] Fully pre-processed gas is piped to one or more floating CLSO’s, which now have much more deck space available. Extra deck space on the CLSO, freed up by removing pre-processing, can be used for additional safety features. Furthermore, possibilities exist for greater liquefaction capacity which will confer additional economic advantages. The extra deck space also opens the possibility of using air cooling instead of seawater cooling, solving the seawater intake and associated environmental issue.

[0011] Air coolers are less efficient and require much larger space compared to seawater cooling. This presents a design challenge even with the extra deck space available on a CLSO. Furthermore, air cooled heat exchangers typically require air temperatures 10 to 15°C below the temperature of the fluid to be cooled. . In normal situations, it would be desirable or required to cool / condense the LNG refrigerants to about 30 to 40°C before the refrigerants are routed to the LNG exchangers. However, in temperate areas, design ambient air temperature may be relatively high such as 32°C (90°F) or higher, and it is anticipated that the approach temperature for the air cooled heat exchangers should be at least 10°C, preferably 15°C or more. In addition, the deck space on a CLSO is severely limited. Therefore, the footprint of the air cooled exchangers must be minimized.

[0012] This problem can be solved by operating compressor inter-stage coolers at higher temperatures, and compressing the refrigerants, especially any refrigerant which shall condense before return to LNG exchangers, to higher pressure than normal. All cooling and condensation therefore takes place at higher temperatures, enabling efficient air cooling and higher Logarithmic Mean Temperature Difference (LMTD) and higher air cooler approach temperatures. However, all of this significantly reduces the liquefaction efficiency, increases the energy demand and therefore increases the cooling duty, which partly defeats the intention of accomplishing air cooling in the first place, as indicated in Table 1.
The extra footprint required by air cooling may be minimized if the temperature difference between the process fluid and the ambient air is large. This is illustrated in Figure 1, which shows typical air cooled exchanger plot area (footprint) for 100 MW cooling of hydrocarbons, with an ambient temperature of 40°C. For the same duty, higher hydrocarbon outlet temperature reduces the required plot area significantly. Similarly, higher hydrocarbon inlet temperature also reduces the plot area. Cooling to temperatures below ambient temperature of 40°C is not feasible in this

example. In actual practice, cooling to low temperatures is almost always more difficult with air cooling than with water cooling.

[0013] Liquefaction processes are powered by compressors with inter-coolers and after-coolers, as shown much simplified in Figure 2. Low pressure refrigerant enters the first compression stage, is compressed and cooled in an inter-cooler. The refrigerant is then further compressed in a next compression stage, and cooled in an after-cooler. The refrigerant now has high pressure and low enthalpy, and is returned to the liquefaction process. With air cooling, the coolers will have higher outlet temperatures. This increases compressor work by at least three mechanisms.

[0014] First, higher inter-stage temperatures results in higher suction volumes in the next compressor stage and therefore increased compressor duty, even if the refrigerant flow and pressure increase are constant.

[0015] Second, in particular in cases where refrigerant is condensed in the compressor coolers, higher pressure is needed to accomplish condensation at higher temperature, as shown in Figure 3. Figure 3 illustrates the effect of increasing the pressure from e.g. 35 to 52 bara on the condensation temperature for the gas. At 35 bara cooling below 40 °C is necessary for condensation as shown with line a), whereas the condensation is complete at 70 °C at a pressure of 52 bara, as shown by line b).

[0016] Third, when refrigerant is recycled to the liquefaction process with higher temperature, larger flow is needed to provide the same liquefaction capacity. Typically, all of these effects increase the compressor work by roughly 20% when air cooling is used instead of water cooling.

[0017] Numerous liquefaction processes have been developed and are known by people skilled in the art. All use refrigerant compressors and coolers. The liquefaction efficiency is measured as compressor work per kg gas liquefied. Typically, the efficiency of large base-load liquefaction processes with water cooling might be 0.3 kWh/kg LNG. The efficiency of smaller peak-shaving liquefaction processes might be 0.5 kWh/kg LNG. The efficiency depends on the process and on the refrigerant(s).

[0018] Table 1 shows a comparison of work and cooling duty for two liquefaction processes with water and air cooling. Liquefaction rate is 400 metric tons per hour, the feed gas is at 60 bara and 25°C, and consists of 98 mole% methane, 1.5 mole% ethane and 0.5 mole% propane:

System	Water cooled				Air cooled			
	Efficiency (kWh/kg)	Compr duty (MW)	Enthalpy change (MW)	Cooling duty (MW)	Efficiency (kWh/kg)	Compr duty (MW)	Enthalpy change (MW)	Cooling duty (MW)
Base load	0.3	120	92.9	212.9	0.36	144	92.9	236.9
Peak shaving	0.5	200	92.9	292.9	0.6	240	92.9	332.9

Table 1
Comparison of work and cooling duty for two liquefaction processes

[0019] Air cooling increases the overall cooling duty by 10 to 15%. The air cooler footprint increases by roughly the same amount. In addition, air coolers require power to drive air fans, typically about 2 to 3 MW for the examples in Table 1.

[0020] In addition to increased compressor work and reduced liquefaction efficiency, which result in increased cooling duties when air coolers are employed, there are two other and potentially more severe problems.

[0021] First, the increased refrigerant temperature from compressor after-coolers, limited by the capability of air coolers and the temperature of the ambient air, significantly increases the amount of heat that must be transferred within the LNG heat exchangers where pre-processed natural gas is liquefied. This is because more heat must be transferred from the incoming, pressurized refrigerant in the LNG exchanger to the expanded, cold refrigerant in order to get sufficient pre-cooling of the pressurized refrigerant before expansion. This pre-cooling duty is therefore much larger, resulting in a larger LNG exchanger. There is an upper limit to the size of LNG exchangers. Hence, more units might be needed for the same liquefaction duty, which requires extra space, or the liquefaction capacity is reduced, which has severe economic consequences.

[0022] Second, there is a safety issue with air cooling, if flammable refrigerant is distributed, in large pipe networks and over very large areas, to a considerable number of air coolers. It would be much better to keep any flammable and volatile refrigerant within a small, safe area such as is the case with water cooling.

[0023] An object of the present invention is to provide a method and a system for generation of LNG from natural gas on Coastal Liquefaction, Storage and Offloading (CLSO) facilities that allows for minimized LNG exchanger duty and hence maximum production using air coolers, while at the same time minimizing any safety concerns. Other objects will be clear for the skilled person reading the present description and claims. Accordingly, an efficient base load liquefaction system should be employed, with safe air cooling where flammable refrigerants are confined to a small, safe area, where air cooling does not increase the LNG exchanger duty compared to similar water cooled systems, and with all gas pre-processing located on separate platforms or floaters, or on shore.

Summary of invention

[0024] The present invention relates to a method for liquefaction of a pre-processed natural gas to produce LNG, where pre-processed natural gas and a liquefied and/or cooled primary refrigerant are introduced separately into a LNG heat exchanger where the pre-processed natural gas is liquefied by cooling against the evaporating and/or heating primary refrigerant , where evaporated and/or heated primary refrigerant is withdrawn from the LNG heat exchanger and re-liquefied and/or compressed by compression in a series of compressor steps, where the compressed gas from each compression step is cooled by means of heat exchangers, wherein an aqueous cooling medium cooled in an array of air coolers, is used for cooling of the primary refrigerant.

[0025] According to a first embodiment, the evaporated primary refrigerant is compressed to a pressure of 45 to 65 bara and condensed at said pressure. Operation at said pressure, makes it possible to complete the condensation at temperatures from about 60 °C, at about 70 °C, or higher, which makes it possible to use air coolers even in hot climate, where the ambient temperature may exceed 40 °C, temperatures which makes it impossible to use air coolers in conventional plants at pressures of e.g. 35 bara, where temperatures lower than 40 °C is needed for condensation. See figure 3.

[0026] According to another embodiment, the compressed and cooled refrigerant is further cooled by means of a secondary refrigerant in coolers 16, 16'. Further cooling after compression and cooling by means of an aqueous refrigerant reduces the duty of the LNG heat exchanger, or makes it possible to produce / liquidize more LNG at the same LNG heat exchanger duty.

[0027] According to a further embodiment, the secondary refrigerant cools the primary refrigerant by evaporation in the coolers (16, 16'), and the secondary refrigerant is compressed, cooled in an array of air coolers before being expanded before being expanded for further cooling of the secondary refrigerant. The secondary refrigerant operates in a heat pump circuit where additional cooling effect from air coolers are obtained for further cooling of the primary refrigerant to reduce the duty of the LNG heat exchanger by creating cooling efficiency that would else be possible only by means of water cooling or by air cooling in cold climate.

Brief description of drawings

[0028]

Figure 1 is a plot of air cooled exchanger footprint for obtaining a set hydrocarbon outlet temperature after cooling at different hydrocarbon inlet temperatures,

Figure 2 is an illustration of a compressor train comprising two compression stages with air cooled inter-cooler and after-coolers,

Figure 3 is an illustration of the condensation temperature and pressure for an exemplary refrigerant,

Figure 4 is an illustration of a natural gas liquefaction plant with air cooling using circulating water as cooling medium for cooling at high temperatures and non-flammable, non-toxic and non-ozone depletion refrigerant as cooling medium for cooling at lower temperatures, and

Figure 5 is an illustration of a natural gas liquefaction plant with air cooling using circulating water as cooling medium for cooling at high temperatures and non-flammable, non-toxic and non-ozone depletion refrigerant as cooling medium for cooling at lower temperatures including cooling of pre-processed natural gas.

Detailed description of the invention

[0029] LNG plants according to the present invention will be located on offshore floaters. The floaters will receive pre-treated natural gas from a remote location, which may be pre-treatment facilities on an offshore terminal, a barge or other floater, or land based facilities.

[0030] The full pre-treatment of the natural gas at the remote location normally comprises but is not limited to:

1. Hg removal,
2. gas sweetening, i.e. removal of unwanted acid gases from the natural gas,
3. dehydration, i.e. removal of water that may otherwise cause formation of hydrates from the gas,
4. full or partial NGL extraction and processing, i.e. separation of the NGL from the gas, and optional fractionation of the NGL into saleable products, which depending on the NGL composition might be Liquefied Petroleum Gas (LPG) consisting mainly of propane and butane, and a heavier C5+ fraction.

[0031] Onboard the floater, the pretreated gas is liquefied by cooling to about -163°C. The liquefaction plants as such will be based on known technology, preferably efficient base-load systems, but less efficient peak-shaving systems may also be employed. Known refrigerants for LNG, such as hydrocarbons or nitrogen, will circulate in a circuit comprising compressors, compressor inter-coolers and after-coolers, and LNG exchangers. Depending on the refrigeration system, refrigerants may or may not condense in the compressor coolers before being routed to the LNG exchangers.

[0032] Figure 4 illustrates an embodiment of the present invention. Single mixed refrigerant (SMR) liquefaction process is assumed. Pre-treated natural gas arrives to the floater and is introduced into the LNG plant onboard the floater in a gas pipe 1. The gas in line 1 is introduced into a LNG heat exchanger 2. In the LNG heat exchanger 2 the gas is cooled, liquefied and sub-cooled by heat exchanging with a cold refrigerant as will be further described below. The liquefied and sub-cooled gas exits the LNG exchanger in pipe 3, where it has an enthalpy close to the enthalpy of LNG at atmospheric pressure. The pressure is then reduced to near atmospheric in a valve 4. People skilled in the art will understand that the resulting LNG in pipe 5 will be post-processed, stored in intermediate storage tanks and finally exported in shuttle tankers.

[0033] Compressed, cooled and fully or partly condensed refrigerant in a cold refrigerant line 17 is introduced to LNG exchanger 2, where it is further cooled and, if required, fully condensed. Following this cooling, the refrigerant is expanded in valve 7, which further reduces the temperature, and, most importantly, enables boiling at low temperatures. The cold and expanded refrigerant flows via pipe 8 through LNG exchanger 2. In this process, the refrigerant is gasified and heated.

[0034] The heated and gasified refrigerant is withdrawn from the LNG exchanger in refrigerant pipe 9, which routes the refrigerant to serially arranged main compressors 10, 10´ and 10´´ in which the refrigerant is compressed in a series of compressions. Due to the heating caused by compression heat exchangers 11, 11' and 11", are arranged after each compressor to cool the compressed refrigerant to a temperature of e.g. about 70°C. The heat exchangers are normally located in an area comprising equipment containing hydrocarbons, i.e. LNG and / or the pre-treated natural gas for LNG production, an area which is classified as a hazardous area. Accordingly, a non-flammable, non-toxic high heat capacity liquid such as water, is preferably used as a cooling medium for the heat exchangers 11, 11´ and 11´´.

[0035] This cooling medium is withdrawn from the heat exchangers 11, 11´, 11´´ in a cooling medium recycle pipe 27 and is introduced into an array of air coolers 14 that are arranged in a non-hazardous area. In the air coolers 14, the cooling medium is cooled to the lowest possible temperature allowed by space available for air coolers 14, air cooler efficiency and air temperature. Cooling medium from air cooler 14 is pumped in pump 15 to overcome frictional pressure losses, and re-distributed to each of the heat exchangers 11, 11’ and 11” in cooling medium recycle pipe 27’.

[0036] Knock-out drums 12, 12’ are arranged downstream of the coolers 11, 11’in the path of the gasified refrigerant to remove liquid from the gaseous phase to avoid two-phase flow in the compressors 10´, 10´´ and 10´´´. The liquid removed from the gas phase in the knock-out drums is pumped in pumps 13 and 13’ and is subsequently mixed with the refrigerant exiting the last compressor stage 10´´ via a liquid bypass pipe 28.

[0037] The duty of LNG exchanger 2 is to a high degree determined by the temperature of compressed refrigerant in line 17. A two stage refrigeration system, which cools the compressed refrigerant in heat exchangers 16 and 16’ is arranged in the path of the refrigerant downstream of cooler 11”. Coolers 16 and 16’ use a non-flammable, non-toxic and non-ozone depletion and low global warming potential refrigerant, similar to some refrigerants used in buildings. This refrigerant is called “secondary refrigerant” in the following, to distinguish it from the primary refrigerant used in the LNG exchanger. The secondary refrigerant will work in about the same pressure and temperature range as residential air conditioning systems. Examples of refrigerants applicable as secondary refrigerants are R-410A and R-407C and others under development, replacing the familiar ozone depleting R-22.

[0038] The secondary refrigerant is compressed as will be described below, and is cooled in an array of air coolers 20 where cooling, condensation and sub-cooling take place. These air coolers can be located outside safe areas since the secondary refrigerant is non-flammable or nearly non-flammable. Most of the heat is removed from the secondary refrigerant in the condensation process, which occurs at a nearly constant and relatively high temperature such as about 70°C. This gives a relatively high air cooler LMTD, even in warm climates, enabling efficient cooling.

[0039] The condensed and sub-cooled secondary refrigerant cooled in coolers 29, is led to the LNG system safe area in a secondary refrigerant pipe 31, and expanded in valve 21, for example to a pressure of about 14 bara. At this pressure, the boiling point of the secondary refrigerant is much lower, such as 35°C. The secondary refrigerant is then used as cooling medium in heat exchanger 16, where primary (LNG) refrigerant is cooled to intermediate temperatures such as 45°C. In this process, the secondary refrigerant is only partly vaporized, such as about 50%.

[0040] The partly vaporized secondary refrigerant from heat exchanger 16 is withdrawn through a secondary refrigerant return line 31' and introduced into a liquid knock-out drum 19. Gaseous refrigerant separated in the knock-out drum 19 is withdrawn through a gaseous refrigerant line 32, and thereafter compressed, as will be further described below.

[0041] Liquid from knock-out drum 19 withdrawn through a liquid secondary refrigerant line 30 and is expanded in valve 22 to lower the pressure such as to about 5 bara and introduced into a heat exchanger 16' for further cooling of the primary refrigerant. At this pressure, the boiling point of the secondary refrigerant might be about 0°C, which is sufficient to cool the primary (LNG) refrigerant to about 15 °C. Vaporized secondary refrigerant from heat exchanger 16' is withdrawn through a refrigerant line 30' and is optionally introduced into a liquid knock-out drum 19'. Normally, there will be no liquid from knock-out drum 19'. The gaseous refrigerant in line 30' is introduced into a compressor 18', either directly from line 30' or via the knock-out drum 19', and is compressed typically to a pressure of about 14 bara.

[0042] The gaseous refrigerant compressed in compressor 18' is withdrawn through a line 32', is mixed with the gaseous refrigerant in line 32, and the mixed gaseous refrigerant is introduced into a compressor 18, to be compressed to a pressure of about 30 bara. The compressed secondary refrigerant leaving compressor 18 is then introduced into the above-mentioned array of air coolers 20, to complete the secondary cooling circuit.

[0043] Table 2 shows examples for the first embodiment of the present invention. It refers to Figure 4, and the purpose is to illustrate how the duty of the LNG exchanger is reduced when the main refrigerant temperature, line 17 in Figure 4, is reduced. The examples are based on the liquefaction of pre-processed natural gas with composition 98.0 mole% methane, 1.5 mole% ethane and 0.5 mole% propane. The gas flow is 400 metric tons per hour. Temperature of ambient air is 32°C in all cases, and the pre-processed gas temperature is 25°C. This air temperature would normally enable cooling of the main refrigerant (line 17, Figure 4) to about 45°C but not lower.

[0044] The first column in Table 2 shows equipment reference numerals, which correspond to numerals in Figure 4. The second column describes the equipment. The third and fourth columns show variables and units, respectively.

[0045] Results are shown for four cases. The first case shows main compressor, item 10 in Figure 4, after-cooler discharge temperature of 45°C. This is a reference case obtainable either with the present invention or with direct cooling of the LNG refrigerant in air coolers. The next three cases show results with successive reduction of the main compressor after-cooler discharge temperature to 30, 15 and 0°C, respectively. With an ambient temperature of 32°C, none of these temperatures would be obtainable by direct cooling of the LNG refrigerant in air coolers.

Item	**Description**	**Variable**	**Unit**	**Results**			
17	Main compressor discharge	Temperature	°C	45	30	15	0
10	Main compressor	Duty	MW	150.1	136.7	123.0	112.0
18	Secondary compressor	Duty	MW	7.1	12.8	22.4	36.1
2	LNG exchanger	Natural gas inlet temp	°C	25	25	25	25
		Approach	°C	2.4	2.3	2.4	2.4
		LMTD	°C	5.4	5.3	4.4	4.1
		Total duty	MW	346.3	302.4	264.0	233.1
		Duty reduction	%	0	12.7	23.8	32.7
14	Air cooler (water circuit)	Duty	MW	188.1	153.9	124.0	102.3
		LMTD	°C	20.3	20.3	20.3	20.3
		Footprint	m2	1985	1624	1309	1080
20	Air cooler (refrigerant circuit)	Duty	MW	59.3	85.6	111.3	135.7
		LMTD	°C	20.3	20.3	24.0	32.3
		Footprint	m2	626	904	994	900
14+20	Air coolers	Total footprint	m2	2611	2528	2303	1980
10+18	Compressors	Total duty	MW	157.2	149.5	145.4	148.1

Table 2

Examples, first embodiment of the present invention

[0046] With main compressor discharge temperature 45°C, the LNG exchanger total duty is 346.3 MW. Reduction of this temperature to 30, 15 and 0°C lowers this duty to 302.4, 264.0 and 233.1 MW, respectively. This lower duty can be used to increase the liquefaction capacity, bringing the duty back up to the maximum value of 346.3 MW. The increased liquefaction rate has a significant and positive economic impact.

[0047] As shown in Table 2, this advantage is achieved without increase in air cooler total footprint or increase in total compressor power. At the same time, the safety of the liquefaction system is significantly improved in that no flammable fluid is routed out of the liquefaction plant safe area. Instead, non-flammable fluids are distributed in the air cooler pipe network.

[0048] A second embodiment of the present invention is shown in Figure 5. The second embodiment differs from the first embodiment in that a part of the refrigerant in line 30 downstream of valve 22, is withdrawn via a gas cooler line 25 and led into a gas cooler 23 arranged on the gas pipe 1 to cool the incoming gas. Gasified refrigerant is withdrawn from the gas cooler 23 in a refrigerant return line 25 and is combined with the gas in line 30’ and compressed in compressor 18’ as described above, optionally after liquid separation in knock-out drum 19’.

[0049] Table 3 shows examples for the second embodiment of the present invention. It refers to Figure 5, and the purpose is to illustrate how the duty of the LNG exchanger is reduced when, in addition to reducing the main refrigerant temperature, the temperature of the pre-processed natural gas feed is also reduced. Similar to the examples for the first embodiment of the present invention, the examples are based on the liquefaction of pre-processed natural gas with composition 98.0 mole% methane, 1.5 mole% ethane and 0.5 mole% propane. The gas flow is 400 metric tons per hour. Temperature of ambient air is 32°C in all cases.

[0050] However, the temperature of the natural gas feed to the LNG exchanger, line 1, is now reduced from the previous 25°C. It has now been set to the same numerical value as for the primary refrigerant in line 17, which is 15 and 0°C, respectively.

[0051] The first column in Table 3 shows equipment reference numerals, which correspond to numerals in Figure 5. The second column describes the equipment. The third and fourth columns show variables and units, respectively.

[0052] Results are shown for two cases. The first case shows main compressor, item 10 in Figure 5, after-cooler discharge temperature of 15°C. The next case shows results when the after-cooler 16 discharge temperature is reduced to 0°C.

Item	**Description**	**Variable**	**Unit**	**Results**	
17	Main compressor discharge	Temperature	°C	15	0
10	Main compressor	Duty	MW	120.7	91.4
18	Secondary compressor	Duty	MW	23.0	33.8
2	LNG exchanger	Gas inlet temp	°C	15	0
		Approach	°C	2.4	2.4
		LMTD	°C	4.4	4.4
		Total duty	MW	257.2	191.2
		Duty reduction	%	0	25.6
14	Air cooler (water circuit)	Duty	MW	120.9	83.9
		LMTD	°C	20.3	20.3
		Footprint	m2	1276	885
20	Air cooler (refrigerant circuit)	Duty	MW	112.8	124.0
		LMTD	°C	24.0	32.3
		Footprint	m2	1007	932
14+20	Air coolers	Total footprint	m2	2283	1817
10+18	Compressors	Total duty	MW	143.7	125.2

Table 3

Examples, second embodiment of the present invention

[0053] With both main compressor discharge temperature, line 17, and natural gas feed temperature, line 1, are 15°C, the LNG exchanger total duty is 257.2 MW. Reduction of these temperatures 0°C lowers this duty to 191.2 MW. This lower duty can be used to increase the liquefaction capacity, bringing the duty back up to the maximum value of 346.3 MW (Table 2). The increased liquefaction rate has a significant and positive economic impact.

[0054] As shown in Table 3, this advantage is achieved without increase in air cooler total footprint or increase in total compressor power. At the same time, the safety of the liquefaction system is significantly improved in that no flammable fluid is routed out of the liquefaction plant safe area. Instead, non-flammable fluids are distributed in the air cooler pipe network.

[0055] For a person skilled in the art, and depending on permits and environmental conditions, it would be possible to optimize the system by partial use of sea water for cooling, for example using a submerged pipe in which hot water is introduced, flows and is cooled by conduction of heat to the surrounding sea water, exits and is returned to the process for re-use as coolant, by locating the air coolers at a remote space such as an offshore platform, a barge or on shore, by use of more than two stages of secondary refrigerant cooling, or use of secondary refrigerant for compressor inter-stage cooling in addition to after-cooling, by including gas turbine inlet air cooling as part of the secondary refrigerant circuit, by letting a secondary refrigerant circuit serve more than one gas liquefaction plant, by using alternative liquefaction processes such as N2 refrigerant for smaller systems and C3MR or DMR for base load systems, and by water spray at the air intake to selected air coolers which would reduce the air temperature to the wet bulb temperature. In addition, power production for the CLSO may be partly done on the terminal and the power transferred to the CLSO via sub-sea cable. Furthermore, a person skilled in the art it would understand that heat exchangers 11, 11’, 11” can be substituted with air cooler(s) for direct cooling at these locations.

Claims

1. A method for liquefaction of a pre-processed natural gas to produce LNG, where pre-processed natural gas and a liquefied and/or cooled primary refrigerant are introduced separately into a LNG heat exchanger where the pre-processed natural gas is liquefied by cooling against the evaporating and/or heating primary refrigerant , where evaporated and/or heated primary refrigerant is withdrawn from the LNG heat exchanger and re-liquefied and/or compressed by compression in a series of compressor steps, where the compressed gas from each compression step is cooled by means of heat exchangers, wherein an aqueous cooling medium cooled in an array of air coolers, is used for cooling of the primary refrigerant.
2. The method of claim 1, wherein the evaporated primary refrigerant is compressed to a pressure of 45 to 65 bara and condensed at said pressure.
3. The method of claim 1 or 2, wherein the compressed and cooled refrigerant is further cooled by means of a secondary refrigerant in coolers (16, 16').
4. The method of claim 3, wherein the secondary refrigerant cools the primary refrigerant by evaporation in the coolers (16, 16'), and the secondary refrigerant is compressed, cooled in an array of air coolers before being expanded before being expanded for further cooling of the secondary refrigerant.

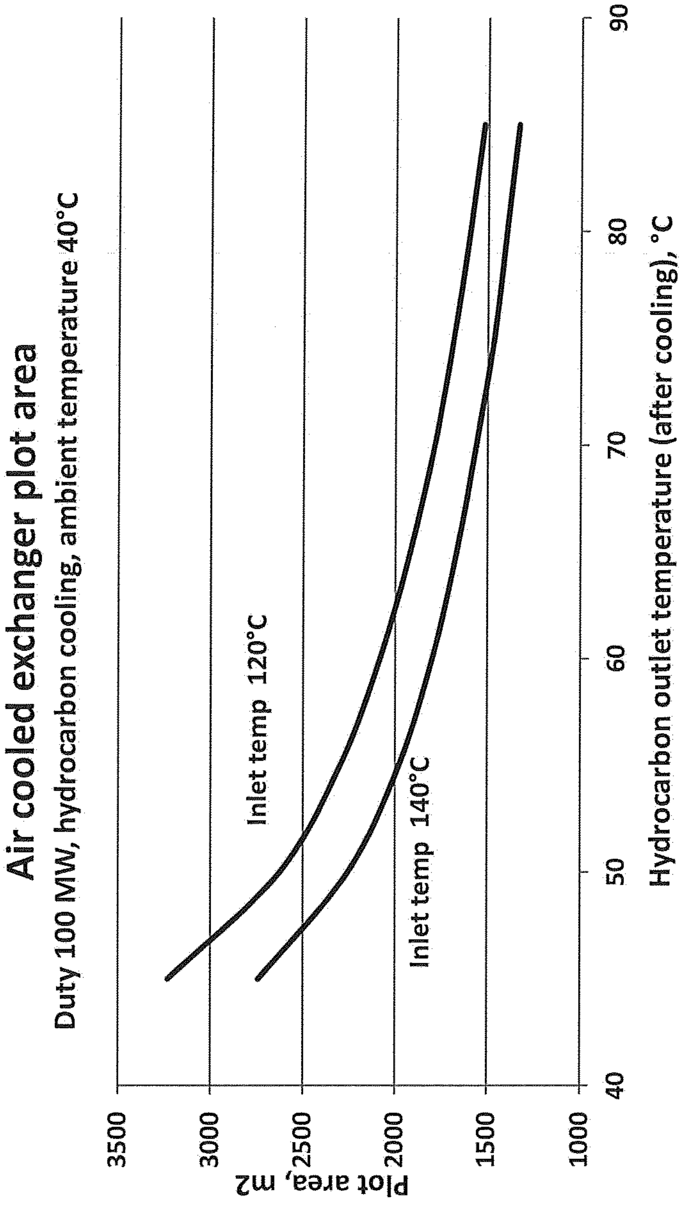

Air cooled exchanger plot area
Duty 100 MW, hydrocarbon cooling, ambient temperature 40°C
Inlet temp 120°C
Inlet temp 140°C
Plot area, m2
3500
3000
2500
2000
1500
1000
40
50
60
70
80
90
Hydrocarbon outlet temperature (after cooling), °C

Fig. 1

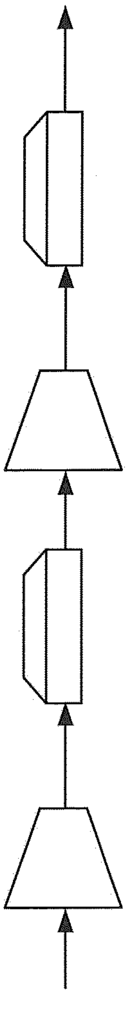
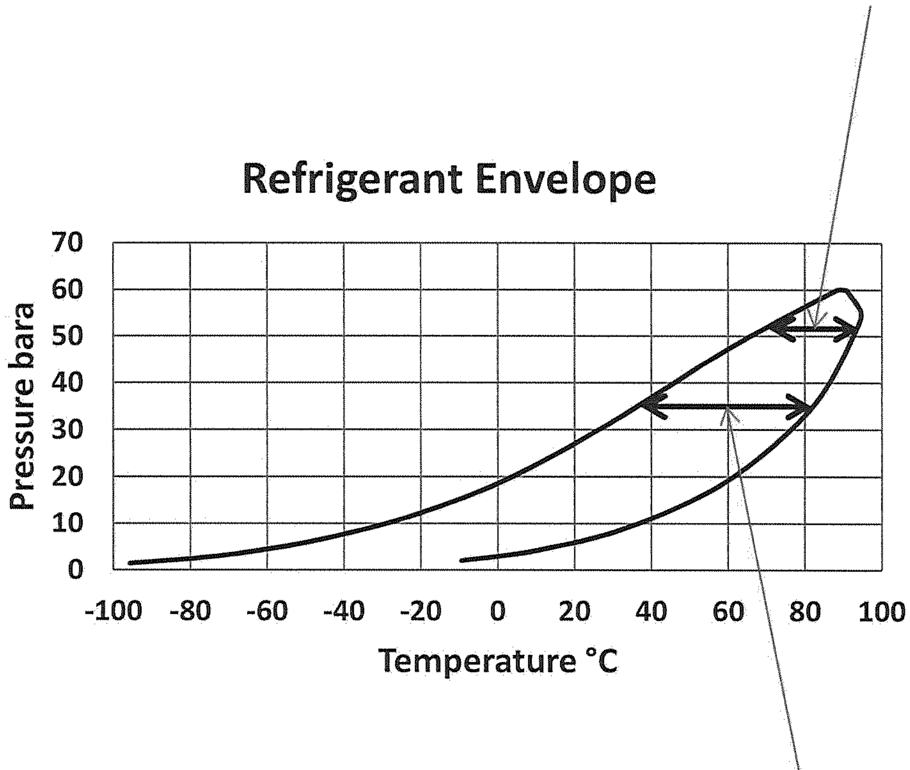


Fig 2

Operation at higher pressure enables condensation
At higher temperature Condensation is complete
at 70 deg C.



Conventional.
Cooling to below 40 C needed for condensation

Fig. 3

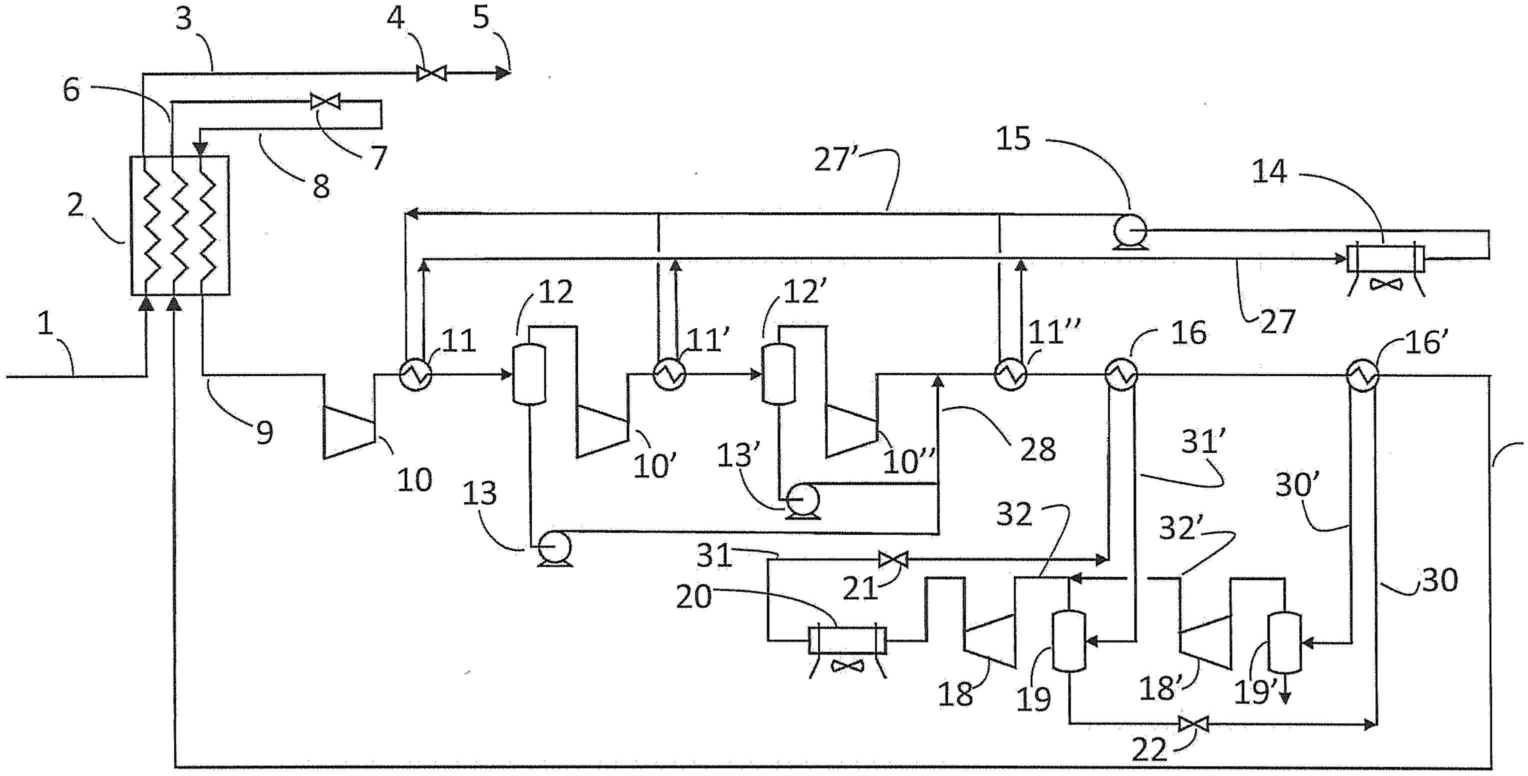

3
4
5
6
7
8
2
27'
15
14
12
12'
1
11
11'
11''
16
16'
27
9
10
10'
13'
10''
28
31'
17
13
32
30'
32'
31
21
30
20
18
19
18'
19'
22

Fig. 4

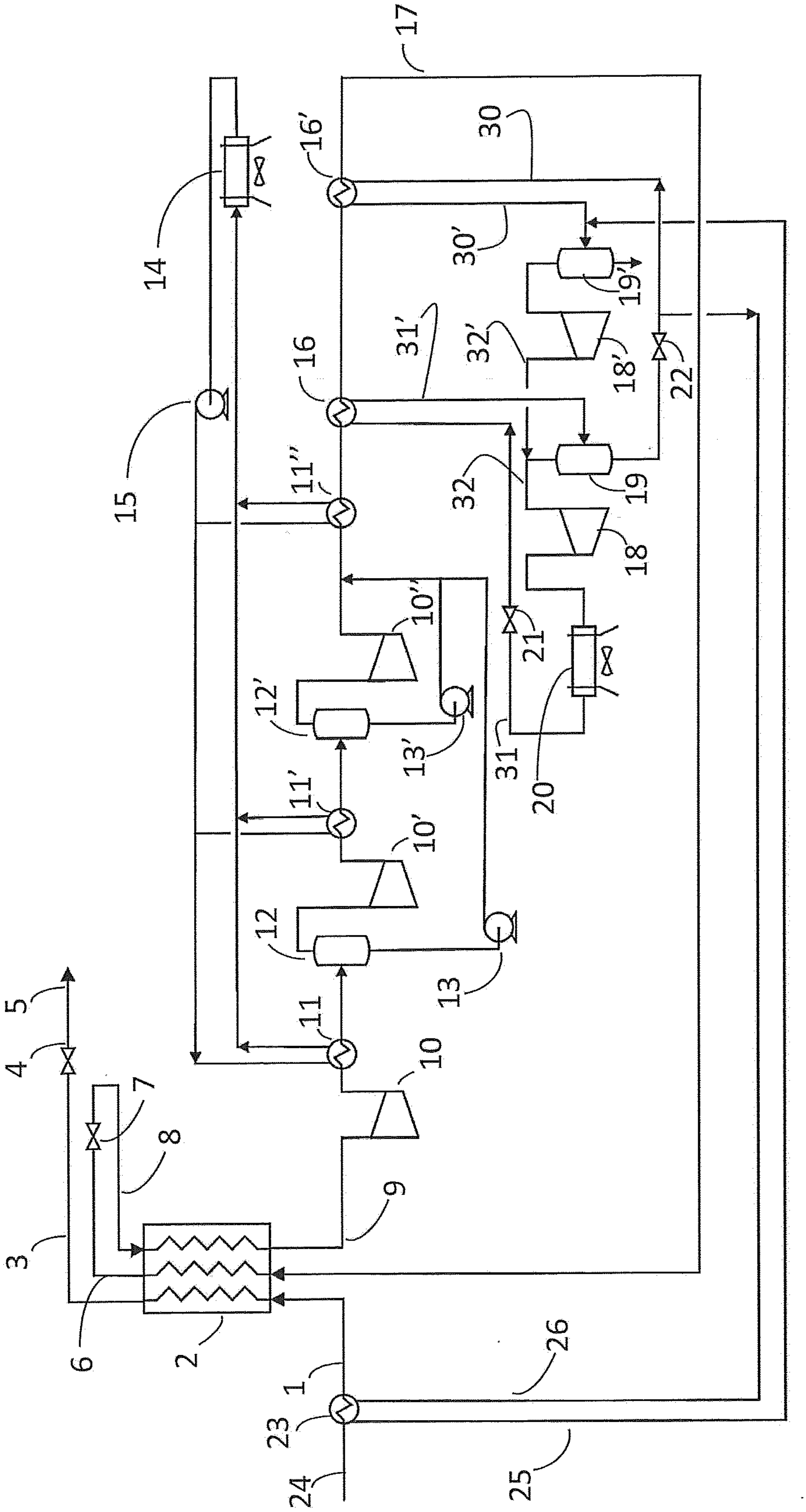

17
16'
30
14
30'
19'
31'
32'
16
18'
22
15
11''
32
19
18
10''
21
12'
13'
31
20
11'
10'
12
13
5
4
7
11
10
8
9
3
6
2
1
26
23
24
25

Fig. 5