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METHOD OF COOLING A HYDROCARBON STREAM AND AN APPARATUS
THEREFOR

The present invention relates to a method of cooling a hydrocarbon stream, such as a natural gas stream and to an apparatus therefor.

WO 2008/081018 discloses a natural gas liquefaction system using gas turbines to drive compressors in a first refrigeration cycle, and recovering waste heat from the gas turbines to help power steam turbines to drive the compressors which compress the natural gas stream. The medium and low pressure exhaust steam from the steam turbines can be used to regenerate a substance used in the pre-treatment of the natural gas, such as in the regeneration of the acid gas sorbent, or to provide reboiler heat in a fractionation unit.

The steam network in a natural gas liquefaction plant can consume about 170 ton/hr of water. This can be contrasted with a plant's requirement of 1600 ton/hr of make up water required for cooling. Fresh water suitable for cooling is a scarce resource in many geographical areas, and the provision of water suitable for cooling in the plant may be a significant limitation on plant capacity.

In a first aspect, the present invention provides a method of cooling a hydrocarbon stream, such as a natural gas stream, the method comprising at least the steps of:

(a) heat exchanging a hydrocarbon stream against one or more refrigerant streams to provide a cooled hydrocarbon stream and one or more at least partly evaporated refrigerant streams;

(b) compressing the one or more at least partly
evapourated refrigerant streams in at least one
refrigerant compressor to provide one or more compressed
refrigerant streams;

5 (c) driving one or more turbines to directly mechanically
drive the at least one refrigerant compressor and provide
one or more hot discharge streams from the one or more
turbines; and

10 (d) thermally desalinating a salinated water stream in a
thermal desalination unit with at least a part of the
heat energy derived from at least one of the one or more
hot discharge streams to provide a desalinated water
stream.

15 In a second aspect, the present invention provides an
apparatus for cooling a hydrocarbon stream, such as a
natural gas stream, comprising at least:

20 a first heat exchanger having a first inlet for a
hydrocarbon stream and a first outlet for a cooled
hydrocarbon stream and a second inlet for a refrigerant
stream and a second outlet for an at least partly
evapourated refrigerant stream, the second outlet of the
first heat exchanger connected to the inlet of a
refrigerant compressor, the refrigerant compressor having
an outlet for a compressed refrigerant stream;

25 a turbine to directly mechanically drive at least one
refrigerant compressor, the turbine having a first outlet
for one or more hot discharge streams; and

30 a thermal desalination unit powered by at least a
part of the heat energy from at least one of the one or
more hot discharge streams, said thermal desalination
unit having a first inlet for a saline water stream and a
first outlet for a desalinated water stream.

Embodiments of the present invention will now be described by way of example only, and with reference to the accompanying non-limiting drawings in which:

Figure 1 shows a simplified scheme 1 for a hydrocarbon cooling process, generally involving cooling a hydrocarbon stream such as natural gas according to a first embodiment;

Figure 2 shows a scheme 1 for a hydrocarbon cooling process, generally involving cooling a hydrocarbon stream such as natural gas according to a second embodiment.

For the purpose of this description, a single reference number will be assigned to a line as well as a stream carried in that line. Same reference numbers refer to similar components, streams or lines.

Embodiments of the present invention advantageously integrate a desalination unit into a hydrocarbon cooling apparatus, such as a natural gas liquefaction plant, or a desalination process into a hydrocarbon stream cooling process.

By such integrating it is achieved that desalinated water can be generated using heat from one or more hot discharge streams from the cooling process or apparatus.

The apparatus and methods described herein may provide Liquefied Natural Gas (LNG).

The method and apparatus also provides a desalinated water stream from a salinated water stream utilising a thermal desalination unit.

A hydrocarbon feed stream can be provided which may be any suitable gas stream to be cooled and liquefied, but is usually a natural gas stream obtained from natural gas or petroleum reservoirs. As an alternative the natural gas stream may also be obtained from another

source, also including a synthetic source such as a Fischer-Tropsch process.

Usually a natural gas stream is comprised substantially of methane. Preferably the hydrocarbon feed stream comprises at least 50 mol% methane, more preferably at least 80 mol% methane.

The hydrocarbon feed stream may also contain non-hydrocarbons such as H_2O , N_2 , CO_2 , Hg , H_2S and other sulphur compounds, and the like. If desired, the hydrocarbon feed stream comprising the natural gas may be pre-treated before cooling and any liquefying. This pre-treatment may comprise reduction and/or removal of undesired components such as CO_2 and H_2S or other steps such as early cooling, pre-pressurizing or the like. As these steps are well known to the person skilled in the art, their mechanisms are not further discussed here.

Thus, the term "hydrocarbon feed stream" also includes a composition prior to any treatment, such treatment including cleaning, dehydration and/or scrubbing, as well as any composition having been partly, substantially or wholly treated for the reduction and/or removal of one or more compounds or substances, including but not limited to sulphur, sulphur compounds, carbon dioxide, water, Hg , and one or more C_2+ hydrocarbons.

Depending on the source, natural gas may contain varying amounts of hydrocarbons heavier than methane such as in particular ethane, propane and the butanes, and possibly lesser amounts of pentanes and aromatic hydrocarbons. The composition varies depending upon the type and location of the gas.

Conventionally, the hydrocarbons heavier than butanes are removed as far as efficiently possible from the hydrocarbon feed stream prior to any significant cooling

for several reasons, such as having different freezing or liquefaction temperatures that may cause them to block parts of a methane liquefaction plant. Furthermore, C₂₋₄ hydrocarbons can be separated from, or their content reduced in a hydrocarbon feed stream by a demethaniser, which will provide an overhead hydrocarbon stream which is methane-rich and a bottoms methane-lean stream comprising the C₂₋₄ hydrocarbons. The bottoms methane-lean stream can then be passed to further separators to provide Liquefied Petroleum Gas (LPG) and other condensate streams.

After separation, the hydrocarbon stream should be cooled. The cooling could be provided by a number of methods known in the art. One example is by passing the hydrocarbon stream against one or more refrigerant streams which can be in one or more refrigerant circuits. Such a refrigerant circuit can comprise one or more refrigerant compressors to compress an at least partly evaporated refrigerant stream to provide a compressed refrigerant stream. The compressed refrigerant stream can then be cooled in a cooler, such as an air or water cooler, to provide the refrigerant stream.

The refrigerant compressors can be driven by one or more turbines. At least one of the turbines is used to directly mechanically drive at least one refrigerant compressor to provide one or more hot discharge streams. At least a part of the heat energy derived from at least one of the one or more hot discharge streams from the turbine is used to thermally desalinate a salinated water stream to provide a desalinated water stream. This is discussed in greater detail below.

The cooling of the hydrocarbon stream can be carried out in one or more stages. Initial cooling, also called

pre-cooling, can be carried out using a single refrigerant, e.g. propane, in a pre-cooling refrigerant circuit or a first fraction of a mixed refrigerant of a mixed refrigerant circuit, in one or more pre-cooling heat exchangers, to provide a partially liquefied hydrocarbon stream, preferably at a temperature below 0 °C.

Preferably, any such pre-cooling heat exchangers could comprise a pre-cooling stage, with subsequent cooling being carried out in one or more main heat exchangers to liquefy a fraction of the hydrocarbon stream in one or more main and/or sub-cooling cooling stages.

In this way, the method and apparatus disclosed herein may involve two or more cooling stages, each stage having one or more steps, parts etc. For example, each cooling stage may comprise one to five heat exchangers. The or a fraction of a hydrocarbon stream and/or the mixed refrigerant may not pass through all, and/or all the same, the heat exchangers of a cooling stage.

In one embodiment, the hydrocarbon liquefying process comprises two or three cooling stages. A pre-cooling stage is preferably intended to reduce the temperature of a hydrocarbon feed stream to below 0 °C, usually in the range -20 °C to -70 °C.

A main cooling stage is preferably separate from the pre-cooling stage. That is, the main cooling stage comprises one or more separate main heat exchangers.

A main cooling stage is preferably intended to reduce the temperature of a hydrocarbon stream, usually at least a fraction of a hydrocarbon stream cooled by a pre-cooling stage, to below -100 °C.

Heat exchangers for use as the one or more pre-cooling or the one or more main heat exchangers are well known in the art. At least one of the main heat exchangers is preferably a spool-wound cryogenic heat exchanger known in the art. Optionally, a heat exchanger could comprise one or more cooling sections within its shell, and each cooling section could be considered as a cooling stage or as a separate 'heat exchanger' to the other cooling locations.

In another embodiment described herein, one or more fractions of a mixed refrigerant stream can be passed through one or more heat exchangers, preferably two or more of the pre-cooling and main heat exchangers described hereinabove, to provide one or more cooled mixed refrigerant streams.

The mixed refrigerant in a mixed refrigerant circuit may be formed from a mixture of two or more components selected from the group comprising: nitrogen, methane, ethane, ethylene, propane, propylene, butanes, pentanes, etc. The present invention may involve the use of one or more other refrigerants, in separate or overlapping refrigerant circuits or other cooling circuits.

In one embodiment of the present invention, the method of cooling, preferably liquefying a hydrocarbon stream comprises one refrigerant circuit comprising one mixed refrigerant.

A mixed refrigerant or a mixed refrigerant stream as referred to herein comprises at least 5 mol% of two different components. More preferably, the mixed refrigerant comprises two or more of the group comprising: nitrogen, methane, ethane, ethylene, propane, propylene, butanes and pentanes. A common composition for a mixed refrigerant can be:

	Nitrogen	0-10 mol%
	Methane (C1)	30-70 mol%
	Ethane (C2)	30-70 mol%
	Propane (C3)	0-30 mol%
5	Butanes (C4)	0-15 mol%

The total composition comprises 100 mol%.

In another embodiment, the cooled hydrocarbon stream can be a liquefied hydrocarbon stream. Preferably, the method is for liquefying natural gas to provide liquefied natural gas.

Preferably, the cooled hydrocarbon stream provided by the method and apparatus described herein can be used to provide a liquefied hydrocarbon stream which can be stored in one or more storage tanks.

After liquefaction, the liquefied hydrocarbon stream may be further processed, if desired. As an example, the obtained LNG may be depressurized by means of a Joule-Thomson valve or by means of a cryogenic turbo-expander.

In another embodiment disclosed herein, the liquefied hydrocarbon stream is passed through an end gas/liquid separator such as an end-flash vessel to provide an end-flash gas stream overhead and a liquid bottom stream, the latter optionally for storage in a storage tank as the liquefied product, such as LNG. The end-flash gas can be compressed in an end-flash gas compressor to provide a compressed end-flash gas stream and cooled to provide a cooled end-flash gas stream, which can be passed to one or more fuel gas headers, or for export as fuel gas.

Returning to the one or more refrigerant circuits in the one or more cooling stages, the method and apparatus described herein utilises at least a part of the heat

energy from the one or more hot discharge streams from the one or more turbines driving at least one of the refrigerant compressors to thermally desalinate a salinated water stream in a thermal desalination unit to provide a desalinated water stream.

In a further embodiment, at least one of the one or more turbines can be used to provide one or both of mechanical or electrical power. The electrical power can be provided by mechanically linking the turbine to an electric generator. The electrical power provided can be used throughout the cooling apparatus, for instance to power pumps or electrical drivers, for instance drivers for compressors, particularly refrigerant compressors.

In a preferred embodiment, the one or more turbines can comprise a gas turbine which provides one or more flue gas streams as the hot discharge stream. The flue gas stream can be passed to one or more steam heat exchangers, where it can be heat exchanged against one or more water feed streams to provide one or more high pressure steam streams. The one or more high pressure steam streams can provide heat energy to the thermal desalination unit after pressure reduction in a suitable pressure reduction device.

It is another embodiment the one or more turbines can comprise a steam turbine which can provide one or more heated H₂O streams as the hot discharge stream. The one or more heated H₂O streams can provide heat energy to the thermal desalination unit. The steam turbine can be powered by a high pressure steam feed stream from, for example the boiler, the high pressure steam header or the steam heat exchangers.

Thus, in a further embodiment, a high pressure steam stream is provided. This can be provided by, for example,

a boiler, a high pressure steam header or by heat exchange with the flue gas stream of a gas turbine.

At least one of the one or more high pressure steam streams described above can be provided to a pressure
5 reducing device, such as a Joule-Thomson valve or a steam turbine, to produce a heated H₂O stream. The heated H₂O stream can be used to provide heat energy to the thermal desalination unit.

In another embodiment, at least one or the one or
10 more high pressure steam streams can be passed to a backpressure steam turbine to provide a low pressure steam stream and one or both of mechanical and electrical power. The low pressure steam stream can then be passed to a multi-stage flash distillation unit to provide the
15 desalinated water stream and a condensed steam stream.

Alternatively, the low pressure steam stream can be passed to a condensing steam turbine to provide a hot
water stream and one or both of mechanical and electrical power. The hot water stream can be passed to a multiple-
20 effect evaporator desalination unit to provide a desalinated water stream and a cooled water stream.

In a further embodiment, at least one of the one or more high pressure steam streams can be passed to a
condensing steam turbine to provide a hot water stream
25 and one or both of mechanical and electrical power. The hot water stream can then be passed to a multiple-effect evaporator desalination unit to provide a desalinated water stream and a cooled water stream.

In another embodiment, the mechanical power generated
30 from a turbine, for instance a gas turbine or a steam turbine such as one or both of a backpressure and a condensing steam turbine, can be used to directly mechanically drive at least one refrigerant compressor.

Furthermore, the electrical power generated from a turbine, for instance a gas turbine or a steam turbine such as one or both of a backpressure and a condensing steam turbine, can be used to power at least one electrical refrigerant compressor driver to drive at least one refrigerant compressor.

The thermal desalination unit may be a distillation desalination unit, such as a multiple-stage flash distillation unit or a multiple-effect evaporator desalination unit. The desalination unit provides a desalinated water stream, which in a preferred embodiment can be used to provide at least part of the make-up water stream of the apparatus, such as for example cooling, for instance the cooling of the compressed refrigerant stream.

Such distillation desalination units are advantageous because they do not require extensive pre-treatment of the salinated water stream. Any pre-treatment step may include simple filtration and chlorination (or equivalent operation) of the salinated water stream, the latter step preventing marine growth.

Flash type distillation techniques can provide large capacity desalination plants at low specific heat consumption. Multiple-stage flash desalination units comprise two or more stages. A flash desalination unit stage comprises a thermally insulated chamber holding salinated water. If this salinated water is in equilibrium with its vapour and a flow of a further heated salinated water stream, at a temperature above the equilibrium temperature of the chamber, is added with the pressure being held constant, a proportion of the salinated water fed to the stage will flash providing energy to allow the vaporisation of a quantity of the

stream. The vapour can be condensed on a cooled e.g. salinated water cooled, tube bundle located in the upper part of the chamber. The condensed water can then be caught in a tray below the tube bundle.

5 The temperature of the salinated water in the tube bundle will be raised by the condensation of the water thus providing a heated salinated water stream. The salinated water can be supplied to the tube bundle in the chamber at the same flow rate as the heated salinated
10 water to be desalinated. It is preferred that the heated salinated water stream produced in the tube bundle by the condensation of the water is returned to the chamber as the heated salinated water to be desalinated. The latter operation maintains a constant heat input and withdrawal
15 from the chamber.

 A multiple-stage flash distillation unit comprises a plurality of such stages. After successive heating in the cooling tube bundles of each stage, the heated salinated water is brought to the maximum desired temperature, for
20 instance in the range of 80 to 115 °C by passage through a salination unit heat exchanger. The salination unit heat exchanger provides the heated salinated water with at least a part of the heat energy derived from the one or more hot discharge streams to provide a further heated
25 salinated water stream. The hot discharge stream is preferably a low pressure steam stream and is derived from one or more of the turbines driving at least one of the refrigerant compressors.

 The further heated desalinated water stream is then
30 fed back into the lower part of the hottest stage of the multiple-stage flash desalination unit and is cascaded from one stage to the next while flashing due to the pressure differences between the stages. A concentrated

salt, i.e. brine, stream is provided at the exit from the final stage. The distilled water is also cascaded from one stage to the next and is cooled by steps to provide a desalinated water stream. Energy introduced by the salination unit heat exchanger is rejected at the low temperature end of the multiple-stage flash distillation unit.

An optimal number of stages can be determined for a particular multiple-stage flash desalination unit. In a preferred embodiment, the concentrated salt, i.e. brine, stream exiting the final (lowest pressure) stage can be recycled to the cooling tube bundles in order to limit the amount of make-up water required by the unit.

As an alternative to multiple-stage flash desalination units, multiple-effect evaporator desalination units can be used. Multiple-effect evaporation provides a plurality of thermally insulated chambers comprising a heating tube bundle fed by a heating fluid, such as hot water from a condensing steam turbine. Salinated water is sprayed over the heating tubes at low pressure and the internal heating fluid causes it to boil to produce water vapour. A make-up salinated water stream can be added to the top of the tube bundle in an amount greater than the rate of vaporisation to form a fluid film flowing down the heating tube bundle. Concentrated salinated water, i.e. brine, is collected under the heating tube bundle and extracted by a pump.

The chamber further comprises an injector to maintain the required vacuum level in the chamber. The boiling temperature of water depends upon its pressure, such that the lower the pressure, the lower the boiling temperature will be. The boiling pressure and temperature of each

subsequent chamber should be lower than that of the previous chamber.

The vapour generated when evaporating a salinated water stream in a first and subsequent effect chamber can be removed as a desalinated water stream. In a preferred embodiment at least a part of the vapour from the first effect chamber can be used as the heating fluid for a second effect chamber and so on, allowing the recovery of heat to be repeated several times.

The final chamber should contain a condenser, such as a tube bundle condenser comprising, for instance, cooled salinated water, to condense the water vapour. The condensed water vapour flowing down the condenser is collected in a tray and removed as a desalinated water stream, for instance by a pump.

The maximum brine temperature should not exceed 63 °C in order to avoid the deposit of scale. The temperature in the last chamber should be slightly higher than that of the cooling saline water. Within this temperature range, the number of chambers utilised can be optimised for a particular set of requirements. Four chambers are common, although up to twelve or more chambers may be appropriate.

Multiple-effect evaporator techniques provide multiple advantages. Multiple-effect evaporation desalination units can operate at lower temperatures e.g. about 60 °C, compared to multiple-stage flash desalination units. A lower scaling rate for the former is achieved because the salinated stream flows down the heated bundles by gravity, compared to the forced salinated stream circulation through the condenser tubes of a multiple-stage flash desalination units.

The lower operating temperature of multiple-effect evaporator techniques also provides the advantage that corrosion is reduced such that standard stainless steels or coated carbon steels can be used. In addition, most of the water vapour to be condensed is generated on the heating bundles and not by the flashing of the further heated salinated stream. This controlled evaporation leads to a minimisation of the carry over of salt in the vapour and therefore to a higher purity distillate.

Furthermore multiple-effect evaporators do not require brine recirculation pumps, dispensing with high pressure circuits. Multiple-effect evaporators also have a lower specific heat consumption because the heat introduced into the cycle is used several times. Finally such multiple-effect evaporators can be started up quickly and easily, to provide steady operation, even at partial loadings, and can be provided with a compact design. Consequently, multiple-effect evaporator desalination units are preferred herein.

Referring to the drawings, Figure 1 shows a general scheme 1 for the cooling of a hydrocarbon stream 10, such as a natural gas stream. Hydrocarbon stream 10 is passed to the first inlet 105 of a first heat exchanger 100 where it is heat exchanged against a refrigerant stream 20 passed to a second inlet 120. A cooled hydrocarbon stream 110 is provided at a first outlet and an at least partly evaporated refrigerant stream 60 is provided at a second outlet 115 of first heat exchanger 100. It is apparent to the skilled person that more than one heat exchanger and refrigerant stream may be utilised to cool the hydrocarbon stream 10, as already discussed. The cooled hydrocarbon stream 30 can be a partially or

completely liquefied hydrocarbon stream, such as a LNG stream.

Turning to the refrigerant circuit 5, the partly evapourated refrigerant stream 40 is passed to the first inlet 155 of a refrigerant compressor 150, where it is compressed to provide a compressed refrigerant stream 60 at outlet 160. The compressed refrigerant stream 60 can be passed to a cooler 550, such as an air or water cooler, where it is cooled to provide refrigerant stream 20, which is returned to the second inlet 120 of the first heat exchanger 100.

The refrigerant compressor 150 is directly mechanically driven via shaft 165 by a turbine 200. Turbine 200 can be a gas turbine, or a steam turbine such as a backpressure or condensing stream turbine. Turbine 200 produces a hot discharge stream 220. When the turbine 200 is a gas turbine, hot discharge stream 220 is a flue gas stream. The flue gas stream can be passed to a steam heat exchanger 300, where it is heat exchanged against a water feed stream 310 to provide a high pressure steam stream 230 and a cooled flue gas stream 320. The high pressure steam stream 230 can be passed to a high pressure steam header 500 as shown, or directly to a pressure reducing device 400.

The pressure reducing device 400 can be a Joule-Thomson valve, or a backpressure and/or condensing steam turbine, and reduces the pressure of the high pressure steam stream 230 to provide a heated H₂O stream 460. The heated H₂O stream can be a low pressure steam stream or a hot water stream depending upon the pressure reducing device 400. This is discussed in greater detail below.

In an embodiment not shown in Figure 1, if the turbine 200 is a steam turbine, then the hot discharge

stream 220 can be the heated H₂O stream 460 and there is no requirement for a steam heat exchanger 300 or pressure reduction device 400. This is because the steam turbine performs the function of the pressure reducing device 400.

The heated H₂O stream 460 can be passed to a desalination unit 250, where heat from the heated H₂O stream 460 is used in the desalination of a saline water stream 280. When giving off its heat, the heated H₂O stream 460 is transformed into a cool water stream 270, which may be routed back to the water feed stream 310. The desalination unit has a first inlet 255 for the saline water stream 280, such as a seawater stream, a first outlet 265 for a desalinated water stream 260, and a second inlet 465 for the heated H₂O stream 460 and a second outlet 275 for the cool water stream 270. The preferred types of desalination unit are discussed in greater detail with regard to Figure 2.

Figure 2 shows a general scheme 1 for the cooling of a hydrocarbon stream 10, such as a natural gas stream according to a second embodiment. Those lines and streams of the same number to that of Figure 1 share identical definitions and meanings.

In a similar manner to Figure 1, hydrocarbon stream 10 is cooled in heat exchanger 100 against a refrigerant stream 20 to provide a cooled hydrocarbon stream 30 and an at least partly evaporated refrigerant stream 40. Refrigerant circuit 5 provides three examples of refrigerant compressors 150a, 150b, 150c and associated turbine drivers 200, 450a, 450b.

At least partly evaporated refrigerant stream 40 is compressed in a first refrigerant compressor 150a to provide a first compressed refrigerant stream 60a. First

compressed refrigerant stream 60a is then passed to second refrigerant compressor 150b where it is compressed to provide second compressed refrigerant stream 60b. Second compressed refrigerant stream 60b is then passed to third refrigerant compressor 150c where it is compressed to provide third compressed refrigerant stream 60c. Third compressed refrigerant stream 60c is passed to a cooler 550, such as an air or water cooler, where it is cooled to provide refrigerant stream 20.

It will be clear to the skilled person that three compression operations in a refrigerant circuit may not be required. These are present in the embodiment of Figure 2 to provide three examples of turbine drivers for the refrigerant compressors, and how their hot discharge streams can be used to provide heat energy for a thermal desalination process.

The first refrigerant compressor 150a is directly mechanically driven via shaft 165 by a steam turbine, more particularly a condensing steam turbine 450b. The condensing steam turbine 450b is supplied with a high pressure steam stream 230a from a high pressure stream header 245. The high pressure steam header 245 can be supplied with high pressure steam from a boiler 350, via high pressure steam stream 230b, or from a steam heat exchanger 300 as discussed below.

The condensing steam turbine 450b produces a hot water stream 460c as a hot discharge stream. The hot water stream 460c can be passed to a multiple-effect evaporator desalination unit 250b at second inlet 465b. The operation of a multiple-effect evaporator desalination unit is discussed above, and utilises the hot water stream 460c to desalinate a saline water stream 280b, fed to a first inlet 255b to produce a desalinated

water stream 260b at a first outlet 265b and a cool water stream 270b at a second outlet 275b. The desalinated water stream 260b can be passed to a cooling water stream 290b, preferably as a make-up water stream. The cooling water stream 290b can then be sent to a cooling tower 295b.

Second refrigerant compressor 150b is shown to be directly mechanically driven via shaft 165b by a backpressure/condensing steam turbine 170. Shaft 165b is also connected to first electric generator 900a to provide electrical power which can be used in the apparatus.

The backpressure/condensing steam turbine 170 is supplied with a high pressure steam stream 230c from the high pressure steam header 245. The high pressure steam stream 230c is passed to a backpressure steam turbine stage 450a which converts part of the thermal energy of the stream to mechanical energy. A low pressure steam stream 460a is passed from the backpressure steam turbine stage 450a to a condensing steam turbine stage 450b, where the steam expands below atmospheric pressure and then condenses to heat cooling water in a backpressure stage condenser. The backpressure stage condenser provides a hot water stream 460c which can be passed to a multiple-effect evaporator desalination unit 250b as discussed for the first refrigerant compressor 150a.

The third refrigerant compressor 150c is driven by a shaft 165c connected to a gas turbine 200. The gas turbine 200 comprises a gas turbine compressor stage 200a which compresses an oxidant gas stream 210, such as air, to provide a compressed oxidant gas stream 212. The compressed oxidant gas stream 212 is passed to a combustion chamber 200b. The compressed oxidant gas

stream 212 is mixed with a fuel gas stream 215 in the combustion chamber 200b and ignited to provide a combusted gas stream 217. The combusted gas stream 217 is passed to gas turbine expander stage 200c where it is expanded to perform mechanical work and provide hot discharge stream 220 as a flue gas stream.

Flue gas stream is passed to a steam heat exchanger 300 where it is heat exchanged against a water feed stream 310 to provide a high pressure steam stream 230d and a cooled flue gas stream 320. The high pressure steam stream 320 can be passed directly to a steam turbine 450, or fed to the high pressure steam header 245.

In a further embodiment, Figure 2 shows a backpressure steam turbine 450d supplied by a high pressure steam stream 230e from the high pressure steam header 245. This could also be supplied directly from the boiler 350, or from the steam heat exchanger 300. The backpressure steam turbine 450d is used to mechanically drive a second electric generator 900b via shaft 165d. The second electric generator 900a can supply electrical power to the apparatus.

The backpressure steam turbine 450d produces a low pressure steam stream 460b, which can be used to supply low pressure steam header 545, or can be passed directly to the multiple-stage flash distillation unit 250a at second inlet 465a as a heated H₂O stream.

The operation of a multiple-stage flash distillation unit 250a is discussed above, and utilises the low pressure steam stream 460b fed to a second inlet 465a to desalinate a saline water stream 280a supplied to a first inlet 255a. The multiple-stage flash distillation unit 250a produces a desalinated water stream 260a at a first

outlet 265a and a cool water stream in the form of a condensed steam stream 270a at a second outlet 275a.

The desalinated water stream 260a can be used as a make-up water stream. The cool water stream(s) 270a, 270b
5 may be routed back to the water feed stream 310.

It is remarked that combining a thermal water desalination unit with an electrical generation unit has been proposed in the art, for example in US Patent 3,479,820 and US Patent Application publication
10 No. 2007/0084778. However, the present proposal of integrating a desalination unit and/or process into a hydrocarbon stream cooling process and/or apparatus, for instance in a natural gas liquefaction plant, has a distinct advantage that this allows for numerous
15 opportunities to utilize residual, relatively low quality, heat that is still available in the cool water stream 270, 270a, 270b discharged from the above-described thermal desalination unit 250 as process heat.

Therefore, in a preferred group of embodiments, the
20 method according to the invention comprises using residual heat coming from the thermal desalination unit after the thermally desalinating in step (d) to provide process heat in or for the method of cooling the hydrocarbon stream. Preferably, the process heat is used
25 to heat the hydrocarbon stream upstream of step (a), and/or any part of the hydrocarbon stream extracted from the hydrocarbon stream.

Process heat for the purpose of which the residual heat may be used, may be added to the process via one or
30 more of various types of process heaters, such as for instance a heater (e.g. a reboiler) in a distillation process applied to the hydrocarbon stream or a stream removed therefrom; a hydrocarbon feed gas heater to heat

the hydrocarbon feed gas upstream of step (a); a defrost gas heater; an inlet three-phase separator heater, which separates the hydrocarbon stream to be cooled in step (a) from a multi-phase well fluid stream. Such process heaters, which suitably consume low quality residual heat, are generally not present in a typical electrical power generation plant.

Thus, in the preferred group of embodiments, the thermal desalination unit is coupled to at least one process heater comprised in the apparatus for cooling the hydrocarbon stream.

An example of providing heat to a heater in a distillation process, is to provide heat to a de-methanizer reboiler or a de-ethanizer reboiler. Such de-methanizer and/or de-ethanizer can be used to extract heavier hydrocarbons from the hydrocarbon feed stream prior to step (a), or used to fractionate C₂₋₄ containing natural gas liquids that have been extracted from the hydrocarbon feed stream into pure components.

More specifically, in the embodiment of Figure 1, the cool water stream 270, optionally in the course of being routed back to the feed water stream 310, may be routed to process heater 272 wherein it is further cooled down while giving off at least some of the residual heat is had it as process heat. Upstream of this heater 272, the cool water stream may have a temperature of typically between 70 °C and 100 °C, downstream thereof it may have a temperature of anywhere between ambient temperature and 70 °C, preferably below 50 °C. The process heater 272 is typically a low grade heat consuming heater, for instance one of the group listed above.

The person skilled in the art will understand that the present invention can be carried out in many various

ways without departing from the scope of the appended claims.

C L A I M S

1. A method of cooling a hydrocarbon stream, comprising at least the steps of:

(a) heat exchanging a hydrocarbon stream against a one or more refrigerant streams to provide a cooled hydrocarbon stream and one or more at least partly evaporated refrigerant streams;

(b) compressing the one or more least partly evaporated refrigerant streams in at least one refrigerant compressor to provide one or more compressed refrigerant streams;

(c) driving one or more turbines to directly mechanically drive the at least one refrigerant compressor and provide one or more hot discharge streams from the one or more turbines; and

(d) thermally desalinating a salinated water stream in a thermal desalination unit with at least a part of the heat energy derived from at least one of the one or more hot discharge streams to provide a desalinated water stream.

2. The method of claim 1, wherein the thermal desalination unit is selected from the group consisting of a multiple-stage flash distillation unit and a multiple-effect evaporator desalination unit.

3. The method of any one of the preceding claims, wherein at least one of the one or more turbines in step (c) is a steam turbine and the one or more hot discharge streams comprise one or more heated H₂O streams.

4. The method of any of the preceding claims, further comprising the step of providing one or more high pressure steam streams.

5. The method of claim 4, wherein at least one of the one or more turbines in step (c) is a gas turbine and the one or more hot discharge streams comprise a flue gas stream, further comprising the step of:

(c2) passing the flue gas stream and a water feed stream through one or more steam heat exchangers to provide the one or more high pressure steam streams.

6. The method of claim 4 or claim 5, further comprising the steps of reducing the pressure of at least one of the one or more high pressure steam streams in a pressure reducing device to provide a heated H₂O stream and passing the heated H₂O stream to the thermal desalination unit.

7. The method of claim 6, wherein step (d) includes the step of:

(d1) passing at least one of the one or more high pressure steam streams to a backpressure steam turbine as the pressure reducing device to provide (i) one or both of mechanical and electrical power and (ii) a low pressure steam stream as the heated H₂O stream.

8. The method of claim 7, further comprising the step of:

(d2) passing the low pressure steam stream to a multi-stage flash distillation desalination unit to provide a desalinated water stream and a cool water stream in the form of a condensed steam stream.

9. The method of claim 7, further comprising the steps of:

(d3) passing the low pressure steam stream to a condensing steam turbine as the pressure reducing device

to provide (i) one or both of mechanical and electrical power and (ii) a hot water stream as the heated H₂O stream; and

(d4) passing the hot water stream to a multiple-effect evaporator desalination unit to provide a desalinated water stream and a cool water stream in the form of a cooled water stream.

10. The method of any one of claims 6 to 9, wherein step (d) comprises the steps of:

(d5) passing at least one of the one or more high pressure steam streams to a condensing steam turbine as the pressure reduction device to provide (i) at least one of mechanical power and electrical power and (ii) a hot water stream as the heated H₂O stream; and

(d6) passing the hot water stream to a multiple-effect evaporator desalination unit to provide a desalinated water stream and a cooled water stream.

11. The method of any one of the preceding claims, wherein at least one of the turbines provides mechanical power to directly mechanically drive at least one refrigerant compressor in step (b).

12. The method of any one of the preceding claims, wherein at least one of the turbines further provides electrical power to drive one or more electrical refrigerant compressor drivers, which drives at least one refrigerant compressor in step (b).

13. The method of any one of the preceding claims, further comprising the step of passing at least a part of the desalinated water stream to a make-up water stream for cooling.

14. The method of any one of the preceding claims, wherein the hydrocarbon stream is a natural gas stream

and the cooled hydrocarbon stream is a liquefied natural gas stream.

15. An apparatus for cooling a hydrocarbon stream, comprising at least:

5 a first heat exchanger having a first inlet for a hydrocarbon stream and a first outlet for a cooled hydrocarbon stream and a second inlet for a refrigerant stream and a second outlet for an at least partly evapourated refrigerant stream, the second outlet of the
10 first heat exchanger connected to the inlet of a refrigerant compressor, the refrigerant compressor having an outlet for a compressed refrigerant stream;

 a turbine to directly mechanically drive at least one refrigerant compressor, the turbine having a first outlet
15 for one or more hot discharge streams; and

 a thermal desalination unit powered by at least a part of the heat energy from at least one of the one or more hot discharge streams, said thermal desalination unit having a first inlet for a saline water stream and a
20 first outlet for a desalinated water stream.

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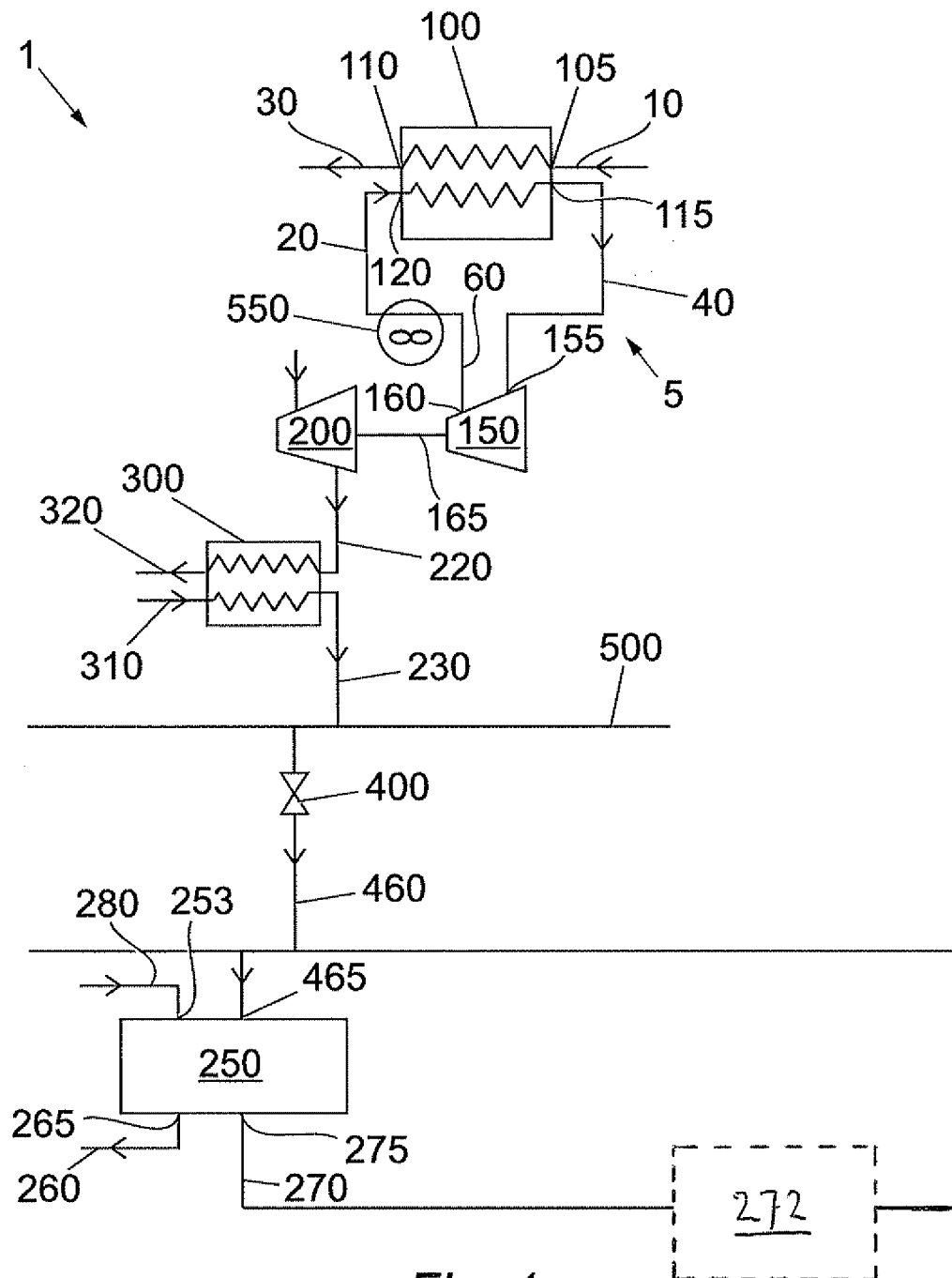


Fig. 1

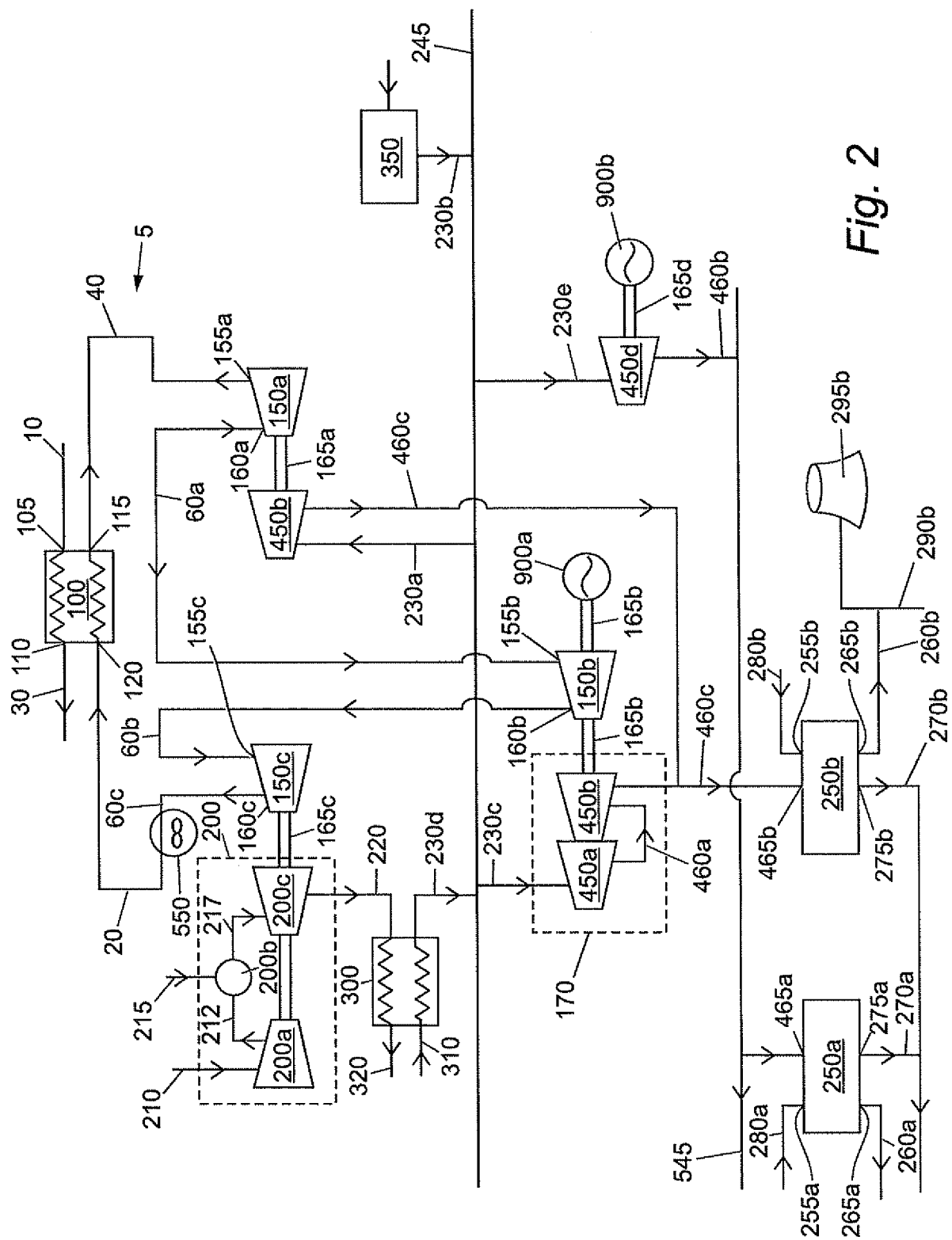


Fig. 2