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(71) Applicant: **Shell Internationale Research
Maatschappij B.V.**
2596 HR Den Haag (NL)

(72) Inventors:
• **Indenkleef, Josephus**
1031 HW Amsterdam (NL)
• **Paulus, Peter Marie**
1031 HW Amsterdam (NL)

(74) Representative: **Matthezing, Robert Maarten**
Shell International B.V.
Intellectual Property Services
P.O. Box 384
2501 CJ The Hague (NL)

(54) **Method and system for producing a cooled hydrocarbons stream**

(57) The pressure of a mixed refrigerant in a selected point in a mixed refrigerant circuit, which relates to the total number of molecules available in the mixed refrigerant circuit, is used to optimize a cooling process. A real time optimization model is employed to calculate a pressure target value for the pressure in a selected point in the mixed refrigerant circuit. The calculation is based on a plurality of measured variables. The power load is kept below a pre-determined maximum power load and while

keeping the discharge temperature below a pre-determined maximum discharge temperature. At least one makeup stream of one of said components is selectively fed to the mixed refrigerant circuit, and/or at least one bleed stream of refrigerant is bled from the mixed refrigerant circuit, whereby decreasing a differential between an actual pressure in said selected point and said pressure target value.

EP 3 032 204 A1

Description

[0001] The present invention relates to a method of producing a cooled hydrocarbon stream. The present invention further relates to a system for producing a cooled hydrocarbon stream.

[0002] A commonly used example of such a cooled hydrocarbon stream is a liquefied natural gas stream. Methods and facilities for producing a cooled hydrocarbon stream, such as a liquefied natural gas stream, typically comprise an automated control system to control and often optimize production of the cooled hydrocarbon stream.

[0003] US Patent 4,809,154 discloses an automated control system for the control of mixed refrigerant-type liquefied natural gas production facilities. With this system, functional parameters are optimized while critical operational limits are concurrently monitored and adjusted. Optimization is accomplished by adjusting parameters including mixed refrigerant (MR) inventory, composition, compression ratio, and compressor turbine speeds to achieve the highest product output value for each unit of energy consumed by the facility. In the case of optimization of MR composition, the setting of the flow ratio controller valve, nitrogen content of the MR, and C3:C2 ratio is done sequentially by an algorithm which attempts to find peak efficiency while adjusting the given parameter. The flow ratio controller valve is a Joule-Thomson valve (JT valve) in the MR liquid line connecting to the warm end spray header, which controls the MR liquid stream. When it is determined that the MR liquid inventory is low, the inventory to be made up is calculated and administered to the refrigeration circuit by opening makeup valves with a timer.

[0004] In accordance with a first aspect of the present invention, there is provided a method of producing a cooled hydrocarbon stream, comprising:

- providing a mixed refrigerant circuit filled with an inventory of a mixed refrigerant, said mixed refrigerant consisting of a mixture of at least two different components;
- circulating the mixed refrigerant as a mixed refrigerant stream through the mixed refrigerant circuit, wherein for a single pass through said mixed refrigerant circuit said circulating successively comprises passing a vaporous refrigerant via a suction drum through a compressor train from a low-pressure side to a high-pressure side whereby increasing a pressure of the vaporous refrigerant in accordance with a compression ratio, passing the vaporous refrigerant at the high-pressure side from the compressor train through a condenser and subsequently from the high-pressure side to the low-pressure side through a pressure-reduction device, and subsequently through a cryogenic heat exchanger wherein the mixed refrigerant stream is allowed to evaporate, and subsequently to the suction drum thereby com-

pleting said single pass;

- passing a hydrocarbon stream through a hydrocarbon stream conduit in said cryogenic heat exchanger in indirect heat exchanging contact with the evaporating refrigerant whereby heat passes from the hydrocarbon stream to the evaporating refrigerant whereby the hydrocarbon stream is cooled thereby forming the cooled hydrocarbon stream;
- driving the compressor train at a power load;
- discharging the cooled hydrocarbon stream from the cryogenic heat exchanger at a discharge temperature;
- calculating a pressure target value for the pressure in a selected point in the mixed refrigerant circuit using a real time optimization model based on a plurality of measured variables including temperatures and pressures in various locations in the mixed refrigerant circuit and the hydrocarbon stream conduit and quality of the vaporous refrigerant, while keeping the power load below a pre-determined maximum power load and while keeping the discharge temperature below a pre-determined maximum discharge temperature;
- selectively feeding at least one makeup stream of one of said components to and/or bleeding at least one bleed stream of refrigerant from the mixed refrigerant circuit whereby decreasing a differential between an actual pressure in said selected point and said pressure target value.

[0005] In accordance with a second aspect of the invention, there is provided a system for producing a cooled hydrocarbon stream, comprising:

- a mixed refrigerant circuit filled with an inventory of a mixed refrigerant, said mixed refrigerant consisting of a mixture of at least two different components, said mixed refrigerant circuit comprising, when considered in a single pass in consecutive order, a suction drum, a compressor train in fluid connection with the suction drum and downstream of the suction drum, a condenser in fluid connection with the compressor train and downstream of the compressor train, a pressure-reduction device in fluid communication with the condenser and downstream of the condenser, and a cryogenic heat exchanger in fluid communication with the pressure-reduction device and downstream of the pressure-reduction device in which cryogenic heat exchanger the mixed refrigerant is allowed to evaporate, whereby the cryogenic heat exchanger discharges into the suction drum thereby completing said single pass, wherein the compressor train forms a first boundary between a low-pressure side and a high-pressure side of the mixed refrigerant circuit and wherein the pressure-reduction device forms a second boundary between the high-pressure side and the low-pressure side;
- a hydrocarbon stream conduit in said cryogenic heat

exchanger in indirect heat exchanging contact with the evaporating refrigerant, for cooling the hydrocarbon stream whereby heat passes from the hydrocarbon stream to the evaporating refrigerant, thereby forming the cooled hydrocarbon stream;

- a driver for mechanically driving the compressor train at a power load;
- a rundown line in fluid communication with the hydrocarbon stream conduit for discharging the cooled hydrocarbon stream from the cryogenic heat exchanger at a discharge temperature;
- a discharge temperature sensor on the rundown line for measuring the discharge temperature;
- a quality measurement instrument to determine the quality of the vaporous refrigerant;
- a control unit comprising a real time optimizer that is arranged to calculate a pressure target value for the pressure in a selected point in the mixed refrigerant circuit using a real time optimization model based on a plurality of measured variables including temperatures and pressures in various locations in the mixed refrigerant circuit and the hydrocarbon stream conduit and quality of the vaporous refrigerant, while keeping the power load below a pre-determined maximum power load and while keeping the discharge temperature below a pre-determined maximum discharge temperature;
- a makeup line for selectively feeding at least one makeup stream of one of said components to and a bleed line for bleeding at least one bleed stream of refrigerant from the mixed refrigerant circuit whereby decreasing a differential between an actual pressure in said selected point and said pressure target value.

[0006] The invention will be further illustrated herein-after by way of example only, and with reference to the nonlimiting drawing in which;

[0007] Fig. 1 schematically shows an example of a method and system for producing a cooled hydrocarbon stream.

[0008] 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. The person skilled in the art will readily understand that, while the invention is illustrated making reference to one or more a specific combinations of features and measures, many of those features and measures are functionally independent from other features and measures such that they can be equally or similarly applied independently in other embodiments or combinations.

[0009] The presently proposed invention uses a mixed refrigerant circuit filled with an inventory of a mixed refrigerant, said mixed refrigerant consisting of a mixture of at least two different components. It is proposed to use the pressure of the mixed refrigerant in a selected point in the mixed refrigerant circuit as additional target representing an additional degree of freedom to optimize the

process. This relates to the total number of molecules available in the mixed refrigerant circuit.

[0010] A real time optimization model is employed to calculate the pressure target value for the pressure in a selected point in the mixed refrigerant circuit. The total number of molecules available in the mixed refrigerant circuit is an additional degree of freedom to be optimized. The optimal number of molecules is then converted to the pressure target value. The calculation is based on a plurality of measured variables including (but not limited to) temperatures and pressures in various locations in the mixed refrigerant circuit and the hydrocarbon stream conduit and quality of the vaporous refrigerant. The power load is kept below a pre-determined maximum power load and while keeping the discharge temperature below a pre-determined maximum discharge temperature. At least one makeup stream of one of said components is selectively fed to the mixed refrigerant circuit, and/or at least one bleed stream of refrigerant is bled from the mixed refrigerant circuit, whereby decreasing a differential between an actual pressure in said selected point and said pressure target value. Bleeding and feeding may be done simultaneously.

[0011] The pressure target value for the pressure in the selected point in the mixed refrigerant circuit is calculated by modeling the process using the real time optimization model based on equations of state, heat and material balances, and heat transfer rates. Once a pressure target value is known, it will be relatively straight forward to selectively feed at least one makeup stream of one of said components to the mixed refrigerant circuit. In some cases, the pressure target value is lower than the actual pressure in which case at least one bleed stream of refrigerant may be bled from the mixed refrigerant circuit.

[0012] It turns out that the effects of mixed refrigerant pressure on maximizing rate of production of the cooled hydrocarbon stream and/or maximizing energy efficiency of producing the cooled hydrocarbon stream are non-linear. Hence the real time optimization model is preferably a non-linear steady-state model to be able to take into account the effects of mixed refrigerant pressure. The preferred real time optimization model is optimizing the non-linear balance between heat transfer efficiencies in the cryogenic heat exchanger and the compression of the vaporous refrigerant while monitoring the relevant constraints, including the effects of changing the mixed refrigerant circuit refrigerant components inventory amount.

[0013] Preferably, the real time optimization model has a plurality of degrees of freedom represented by controlled variables, which can be used to maximize rate of production of the cooled hydrocarbon stream and/or to maximize the energy efficiency of producing the cooled hydrocarbon stream. The real time optimization model calculates target values for each of these controlled variables. These target values are fed to a process control layer module, which translates the target values into ma-

nipulated variables (such as opening or closing of one or more valves) and subsequently executes the manipulated variables.

[0014] In the case of employing the mixed refrigerant to cool and liquefy a stream of natural gas, the mixed refrigerant typically comprises at least nitrogen, methane, C2 and C3. C2 means ethane or ethylene; C3 means propane, propylene, or isopropane. The preferred option for C3 is propane. In such cases, the relative amount of nitrogen and/or C3 present in the running composition of the mixed refrigerant may be additional targets derived from one or two other additional degrees of freedom that can be calculated using the real time optimization model.

[0015] One example of a mixed refrigerant circuit is shown in Fig. 1. The mixed refrigerant circuit 100 shown in this figure is employed to refrigerate a stream of natural gas 10 in a coil wound heat exchanger 20, whereby absorbing heat from the natural gas resulting in condensing and subcooling of the natural gas. This results in a stream of liquefied natural gas 90 being discharged from the coil wound heat exchanger 20 into a rundown line. Natural gas is a valuable example of a hydrocarbon stream, and liquefied natural gas is an example of the cooled hydrocarbon stream.

[0016] The mixed refrigerant circuit 100 is filled with an inventory of a mixed refrigerant, wherein the mixed refrigerant consists of a mixture of at least two different components. The mixed refrigerant circuit comprises in consecutive order, a suction drum 30, a compressor train 40 in fluid connection with the suction drum 30 and downstream of the suction drum 30, a condenser 60 in fluid connection with the compressor train 40 and downstream of the compressor train 40, a pressure-reduction device 80 in fluid communication with the condenser 60 and downstream of the condenser 60, and a cryogenic heat exchanger 20 in fluid communication with the pressure-reduction device 80 and downstream of the pressure-reduction device 80. The compressor train 40 forms a first boundary between a low-pressure side and a high-pressure side of the mixed refrigerant circuit 100, and the pressure-reduction device 80 forms a second boundary between the high-pressure side and the low-pressure side.

[0017] The mixed refrigerant is circulated as a mixed refrigerant stream through the mixed refrigerant circuit. Apart from occasional feeding and/or bleeding, the mixed refrigerant circuit 100 is cyclic. Describing one cycle, the refrigerant passes in vaporous condition to the compressor train 40. The vaporous refrigerant passes through the compressor train 40 from the low-pressure side to the high-pressure side, whereby increasing a pressure of the vaporous refrigerant in accordance with a compression ratio. The vaporous refrigerant passes through the suction drum 30 prior to feeding to the compressor train 40, to ensure that the vaporous refrigerant stream is free from any liquid.

[0018] For the purpose of this description, the compressor train 40 can comprise one compressor or a

number of compressors operating in series (wherein a discharge stream from one of the compressors in the train is fed as input to a next compressor in the train), or in parallel wherein vaporous refrigerant is divided over two or more parallel arranged compressors. The one compressor, any of multiple compressors may comprise a plurality of stages. The compressor train 40 as shown in Fig. 1 by way of example is drawn in as a first stage compressor 41 arranged in series with a second stage compressor 42.

[0019] The vaporous refrigerant stream passes from the first stage compressor 41 to the second stage compressor 42 through an optional inter-stage cooler 44. More stages can be added depending on the desired compression ratio. The compressor train 40 may also be arranged as a single compressor having at least two stages, with or without inter-stage cooling.

[0020] At the high-pressure side the vaporous refrigerant passes at least through the condenser 60, wherein the compressed vapour is at least partially condensed. Optionally, the vaporous refrigerant passes from the compressor train 40 to the condenser 60 though one or more other heat exchangers acting as de-superheaters. This is particularly useful if the other heat exchangers are arranged to pass heat from the vaporous refrigerant stream to an ambient stream such as air or water being fed to the heat exchanger at an ambient temperature. In Fig. 1 the vaporous refrigerant passes from the compressor train 40 to the condenser 60 though an air cooler 50. In such a case, the condenser 60 could be refrigerated to reduce the temperature of the refrigerant stream to below the ambient temperature.

[0021] Subsequently, refrigerant stream passes from the high-pressure side to the low-pressure side through at least the pressure-reduction device. In the case of Fig. 1, the pressure-reduction device comprises a first JT valve which in the case of Fig. 1 is embodied in the form of an HMR JT valve 75, and a second JT valve which in the case of Fig. 1 is embodied in the form of an LMR JT valve 85. As known in the art, JT valve stands for Joule-Thomson valve. Other types of pressure reduction devices, including turbines, may be employed instead of a JT valve or in combination with a JT valve.

[0022] In the example of Fig. 1, the refrigerant stream is partly condensed in the condenser 60 forming a condensed fraction and a vapor fraction, whereby the refrigerant stream consisting of those condensed and vapor fractions passes through a phase separator 70 as it passes from the condenser 60 to the pressure-reduction device. In the phase separator 70 the condensed fraction is separated from the vapor fraction, and discharged as LMR stream 82. LMR stands for "light mixed refrigerant". The condensed fraction is discharged from the phase separator 70 as HMR stream 72. HMR stands for "heavy mixed refrigerant". In this context the terms "light" and "heavy" are used in a relative sense to indicate that the LMR has a lower average molecular weight than the HMR or, conversely, that the HMR has a higher average mo-

lecular weight than the LMR.

[0023] Both the HMR stream and the LMR stream are further cooled in the coil wound heat exchanger 20, whereby the HMR stream 72 is subcooled and the LMR stream 82 is condensed and subsequently subcooled before being passed respectively to the HMR JT valve 75 and the LMR JT valve 85. The HMR JT valve 75 and the LMR JT valve 85 are set in respective valve positions to impose a selected flow rate ratio between the heavy mixed refrigerant stream and the light mixed refrigerant stream. It is stressed here, that not all processes in which the invention is envisaged employ two distinct refrigerant streams such as the HRM and LMR streams and/or two distinct pressure reduction devices as presently shown in the example of Fig. 1.

[0024] On the low-pressure side of the pressure reduction device, the refrigerant stream (in the case of Fig. 1 the LMR stream and the HMR stream) are passed to the cryogenic heat exchanger 20, wherein the mixed refrigerant stream is allowed to evaporate. The refrigerant is then discharged from the cryogenic heat exchanger 20 and subsequently passed to the compressor train 40 through the suction drum 30 whereby completing one single pass of the refrigerant stream through the mixed refrigerant circuit 100. The terms "upstream" and "downstream", "prior to" and "subsequent" in the context of the refrigerant passing through the mixed refrigerant circuit 100 are used assuming a single pass through the mixed refrigerant circuit 100 starting and ending in the suction drum 30.

[0025] The stream of natural gas 10 passes through the cryogenic heat exchanger 20 as well, through a hydrocarbon stream conduit in said cryogenic heat exchanger 20. The stream of natural gas 10 passes through the cryogenic heat exchanger 20 in indirect heat exchanging contact with the evaporating refrigerant, whereby heat passes from the stream of natural gas 10 to the evaporating refrigerant. As a result, the stream of natural gas 10 is cooled, thereby forming the cooled hydrocarbon stream which in the case of the example of Fig. 1 is the stream of liquefied natural gas 90. In any case, the cooled hydrocarbon stream is discharged from the cryogenic heat exchanger at a discharge temperature. The discharge temperature can be determined using a discharge temperature sensor 95. The refrigeration is powered by a driver 48, driving the compressor train 40 at a power load.

[0026] The mixed refrigerant circuit 100 further comprises a pressure sensor 78 sensing an actual pressure of the mixed refrigerant in a selected point in the mixed refrigerant circuit 100. In one set of embodiments the selected point may be in the high-pressure side of the mixed refrigerant circuit 100. In the example of Fig. 1, the pressure sensor 78 senses the actual pressure in the phase separator 70. Nonetheless, in another set of embodiments the selected point may be in the low-pressure side of the mixed refrigerant circuit 100. For instance, the pressure sensor could be arranged such as to sense the

actual pressure in the suction drum 30 (instead of the phase separator 70).

[0027] Finally, the mixed refrigerant circuit 100 comprises a quality measurement instrument (QMI) 45 in fluid communication with the vaporous refrigerant. The QMI is arranged to determine a circulating composition of the mixed refrigerant. Various types of suitable QMIs are known in the art. In the example of Fig. 1, the QMI 45 is arranged to measure the circulating composition between the inter-stage cooler 44 and the second stage compressor 42. However, it may be positioned elsewhere if desired, such as in a refrigerant discharge line 25 extending between the cryogenic heat exchanger 20 and the suction drum 30, or downstream of the compressor train 40 while upstream of the condenser 60.

[0028] Furthermore, the system of Fig. 1 comprises a makeup line 12 for selectively feeding at least one makeup stream of one of the refrigerant components to the mixed refrigerant circuit 100. The system also comprises a bleed line for bleeding at least one bleed stream of refrigerant from the mixed refrigerant circuit. The bleed line may connect to the mixed refrigerant circuit in any suitable point. Generally, it is preferred to connect the bleed line to the mixed refrigerant circuit in a point where vapour free liquid can be bled from the refrigerant circuit. In the example of Fig. 1, two bleed lines are employed: an HMR bleed line 22 and an LMR bleed line 32. Both the HMR bleed line 22 and an LMR bleed line 32 connect to the mixed refrigerant circuit in a point where vapour free liquid can be bled from the refrigerant circuit.

[0029] The system further comprises a control unit 200. The control unit 200 comprises a real time optimizer and a process control layer module. The real time optimizer has a plurality of degrees of freedom which can be converted to controlled variables. These controlled variables can be used to maximize rate of production of the liquefied natural gas and/or to maximize the energy efficiency of producing the liquefied natural gas. The real time optimizer is programmed with a real time optimization model that calculates target values for each of these controlled variables based on a number of measured variables. These target values are fed to a process control layer module, which translates the target values into manipulated variables (such as opening or closing of one or more valves) and subsequently executes the manipulated variables.

[0030] It is currently proposed to employ the pressure of the mixed refrigerant in the selected point in the mixed refrigerant circuit 100 as a controlled variable. The real time optimizer calculates a pressure target value for the pressure in the selected point in the mixed refrigerant circuit, using the real time optimization model. Input to the real time optimization model are a plurality of measured variables including flow rates, temperatures, and pressures, in various locations in the mixed refrigerant circuit and the hydrocarbon stream conduit and quality of the vaporous refrigerant. The power load is kept below a pre-determined maximum power load and the dis-

charge temperature is kept below a pre-determined maximum discharge temperature - these are part of the constraints taken into account by the real time optimization model.

[0031] The plurality of measured variables may comprise flow rate of the cooled hydrocarbon stream, flow rates of the mixed refrigerant, compressor load, and the individual MR inventories as primary degrees of freedom, while all plant measurements (including the mixed refrigerant QMI) are used to determine mismatch between plant and model, and to determine model base performance.

[0032] Depending on the outcome of the calculated target pressure compared to the actual pressure, molecules should be added to the mixed refrigerant circuit to increase pressure or bled from the mixed refrigerant circuit to decrease pressure. Hence, the control unit 200 will selectively manipulate a feed valve 210 and/or a bleed valve (such as an HMR bleed valve 220 and/or an LMR bleed valve 230) to selectively feed at least one makeup stream of one of the refrigerant components to the mixed refrigerant circuit 100 and/or bleed at least one bleed stream of refrigerant from the mixed refrigerant circuit 100. During said selectively feeding or bleeding, a differential between the actual pressure in the selected point (for instance as measured in pressure sensor 78) and the pressure target value is decreased. Which feed valve and/or bleed valve to manipulate may be determined depending on desired values or ranges of the vaporous refrigerant QMI.

[0033] As stated above, in the example of Fig. 1 a selected flow rate ratio between the heavy mixed refrigerant stream and the light mixed refrigerant stream is imposed by the settings of the first JT valve and the second JT valve. A composition ratio between the methane and C2 in the mixed refrigerant is regulated to accommodate to the selected flow rate ratio being imposed. Typically in a mixed refrigerant for producing liquefied natural gas, the degree of condensation in the condenser 60 is governed predominantly by the composition ratio between the methane and C2. The methane and C2 contents in the mixed refrigerant are therefore not derived from degrees of freedom available to the real time optimizer. The real time optimizer does have degrees of freedom to set targets for the nitrogen content and/or the C3 content in the vaporous refrigerant. Alternatively, the nitrogen target is set for the nitrogen content in the LMR stream 82 and/or the C3 target is set for the C3 content in the HMR stream 72. Consequently, in preferred embodiments, a nitrogen target value and/or a C3 target value is also calculated using the real time optimization model (in addition to the pressure target value), wherein the nitrogen target value corresponds to the relative amount of nitrogen in the vaporous refrigerant or the LMR stream, and the C3 target value corresponds to a relative amount of C3 in the vaporous refrigerant or the HMR stream.

[0034] The amount of nitrogen in the mixed refrigerant predominantly determines the bubble point at the cold

end of the cryogenic heat exchanger. The nitrogen target value is strongly dependent on the desired discharge temperature and the desired cold end approach temperature of the cryogenic heat exchanger which impacts the efficiency. The amount of C3 in the mixed refrigerant predominantly can be used to optimize the cooling curve in the part of the cryogenic heat exchanger where the largest heat transfer takes place. The C3 target value influences for instance the superheat temperature at the warm end of the cryogenic heat exchanger.

[0035] The selectively feeding and/or bleeding preferably comprises changing the relative amounts of nitrogen and/or C3 whereby decreasing a differential between an actual nitrogen or C3 content in the vaporous refrigerant and said nitrogen target value or C3 target value. The actual nitrogen and/or C3 contents are determined by the QMI 45 and provided to the real time optimizer to be used as input for the real time optimization model. If the nitrogen and C3 targets refer to the nitrogen and C3 content in the LMR stream and HMR stream, the values as determined by the QMI 45 may simply be converted to nitrogen content in the LMR stream and C3 content in the HMR stream, for instance using a standard flash calculation. Alternatively, specific an LMR QMI and an HRM QMI may be provided to measure the nitrogen and C3 contents in respectively the LMR stream 82 and the HMR stream 72.

[0036] In the case of Fig. 1, nitrogen can be selectively bled from the mixed refrigerant circuit via the LMR bleed line 32 by opening the LMR bleed valve 230 while simultaneously feeding methane into the mixed refrigerant circuit 100 to compensate for the loss of methane through the LMR bleed line 32. Likewise, C3 can be selectively bled from the mixed refrigerant circuit via the LMR bleed line 22 by opening the HMR bleed valve 220 while simultaneously feeding C2 into the mixed refrigerant circuit 100 to compensate for the loss of C2 through the HMR bleed line 22.

[0037] If selectively bleeding is necessary for reducing the actual pressure to meet the pressure target value, both the LMR bleed valve 220 and LMR bleed valve 230 can be opened simultaneously to retain the composition.

[0038] It should be understood that the invention can be used in other types of mixed refrigerant circuits, for cooling natural gas or other types of hydrocarbon streams. Other types of mixed refrigerant circuits may for instance employ a different type of heat exchanger instead of the coil would heat exchanger 20. Any suitable process or liquefaction system wherein a cryogenic heat exchanger is employed may be used in combination with the presently proposed invention. Examples of suitable liquefaction systems may employ single refrigerant cycle processes (usually single mixed refrigerant - SMR - processes, such as PRICO described in the paper "LNG Production on floating platforms" by K R Johnsen and P Christiansen, presented at Gastech 1998 (Dubai); double refrigerant cycle processes (for instance the much applied Propane-Mixed-Refrigerant process, often ab-

breviated C3MR, such as described in for instance US Patent 4,404,008, or for instance double mixed refrigerant - DMR - processes of which an example is described in US Patent 6,658,891.

[0039] Other examples of suitable processes or liquefaction systems are described in: US Patent 5,832,745 (Shell SMR); US Patent 6,295,833; US Patent 5,657,643 (both are variants of Black and Veatch SMR); US Pat. 6,370,910 (Shell DMR). Another suitable example of DMR is the so-called Axens LIQUEFIN process, such as described in for instance the paper entitled "LIQUEFIN: AN INNOVATIVE PROCESS TO REDUCE LNG COSTS" by P-Y Martin et al, presented at the 22nd World Gas Conference in Tokyo, Japan (2003). Suitable three-cycle processes include for example US Pat. 6,962,060; US 2011/185767; US Pat. 7,127,914; AU4349385; US Pat. 6,253,574 (commercially known as mixed fluid cascade process); US Pat. 6,308,531; US application publication 2008/0141711; Mark J. Roberts et al "Large capacity single train AP-X(TM) Hybrid LNG Process", Gastech 2002, Doha, Qatar (13-16 October 2002). These suggestions are provided to demonstrate wide applicability of the invention, and are not intended to be an exclusive and/or exhaustive list of possibilities.

[0040] The invention has been described with particular reference to a mixed refrigerant circuit. Some of the suitable processes or liquefaction systems referred to in the previous paragraphs make use of a pre-cooling mixed refrigerant circuit and a main mixed refrigerant circuit in cascaded relationship with the pre-cooling mixed refrigerant circuit. The Shell DMR process is an example thereof. While it is preferred that the real time optimizer and real time optimizing model as proposed herein is employed to optimize the main mixed refrigerant circuit, it is contemplated that a similar real time optimizer and real time optimizing model as described herein can be employed to a pre-cooling mixed refrigerant circuit.

[0041] As stated in the example, the hydrocarbon stream may be obtained from natural gas or petroleum reservoirs or coal beds. The hydrocarbon stream may also be obtained from another source, including as an example a synthetic source such as a Fischer-Tropsch process, or from a mix of different sources. Preferably the hydrocarbon stream comprise at least 50 mol% methane, more preferably at least 80 mol% methane.

[0042] Depending on the source, the hydrocarbon stream may contain varying amounts of components other than methane and nitrogen, including one or more non-hydrocarbon components other than water, such as CO₂, Hg, H₂S and other sulphur compounds; and one or more hydrocarbons heavier than methane such as in particular ethane, propane and butanes, and, possibly lesser amounts of pentanes and aromatic hydrocarbons.

[0043] If desired, the hydrocarbon stream may have been pretreated to reduce and/or remove one or more of undesired components such as CO₂ and H₂S, or have undergone other steps such as pre-pressurizing or the like. Such steps are well known to the person skilled in

the art, and their mechanisms are not further discussed here. The ultimate composition of the hydrocarbon stream thus varies depending upon the type and location of the gas and the applied pre-treatment(s).

[0044] 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.

Claims

1. Method of producing a cooled hydrocarbon stream, comprising:

- providing a mixed refrigerant circuit filled with an inventory of a mixed refrigerant, said mixed refrigerant consisting of a mixture of at least two different components;
- circulating the mixed refrigerant as a mixed refrigerant stream through the mixed refrigerant circuit, wherein for a single pass through said mixed refrigerant circuit said circulating successively comprises passing a vaporous refrigerant via a suction drum through a compressor train from a low-pressure side to a high-pressure side whereby increasing a pressure of the vaporous refrigerant in accordance with a compression ratio, passing the vaporous refrigerant at the high-pressure side from the compressor train through a condenser and subsequently from the high-pressure side to the low-pressure side through a pressure-reduction device, and subsequently through a cryogenic heat exchanger wherein the mixed refrigerant stream is allowed to evaporate, and subsequently to the suction drum thereby completing said single pass;
- passing a hydrocarbon stream through a hydrocarbon stream conduit in said cryogenic heat exchanger in indirect heat exchanging contact with the evaporating refrigerant whereby heat passes from the hydrocarbon stream to the evaporating refrigerant whereby the hydrocarbon stream is cooled thereby forming the cooled hydrocarbon stream;
- driving the compressor train at a power load;
- discharging the cooled hydrocarbon stream from the cryogenic heat exchanger at a discharge temperature;
- calculating a pressure target value for the pressure in a selected point in the mixed refrigerant circuit using a real time optimization model based on a plurality of measured variables including temperatures and pressures in various locations in the mixed refrigerant circuit and the hydrocarbon stream conduit and quality of the vaporous refrigerant, while keeping the power load below a pre-determined maximum power

- load and while keeping the discharge temperature below a pre-determined maximum discharge temperature;
 - selectively feeding at least one makeup stream of one of said components to and/or bleeding at least one bleed stream of refrigerant from the mixed refrigerant circuit whereby decreasing a differential between an actual pressure in said selected point and said pressure target value.
2. The method according to claim 1, wherein said mixture of at least two different components comprises nitrogen, methane, C2 and C3.
3. The method according to claim 2, further comprising
- calculating a nitrogen target value using the real time optimization model, wherein the nitrogen target value corresponds to a relative amount of nitrogen in the vaporous refrigerant,
- wherein said selectively feeding and/or bleeding comprises changing the relative amounts of nitrogen whereby decreasing a differential between an actual nitrogen content in the vaporous refrigerant and said nitrogen target value.
4. The method according to claim 2 or 3, further comprising:
- calculating a C3 target value using the real time optimization model, wherein the C3 target value corresponds to a relative amount of C3 in the vaporous refrigerant,
- wherein said selectively feeding and/or bleeding comprises changing the relative amounts of C3 whereby decreasing a differential between an actual C3 content in the vaporous refrigerant and said C3 target value.
5. The method according to claim 3 or 4, wherein the vaporous refrigerant is partially condensed in the condenser, thereby forming a condensed fraction and a vapor fraction, whereby a resulting partially condensed refrigerant stream consisting of those condensed and vapor fractions passes through a phase separator when being passed from the condenser to the pressure-reduction device, and wherein the condensed fraction is separated in the phase separator from the vapor fraction whereby the vapor fraction is discharged from the phase separator as a light mixed refrigerant stream and whereby the condensed fraction is discharged from the phase separator as a heavy mixed refrigerant stream.
6. The method according to claim 2, wherein the vaporous refrigerant is partially condensed in the con-

denser, thereby forming a condensed fraction and a vapor fraction, whereby a resulting partially condensed refrigerant stream consisting of those condensed and vapor fractions passes through a phase separator when being passed from the condenser to the pressure-reduction device, and wherein the condensed fraction is separated in the phase separator from the vapor fraction whereby the vapor fraction is discharged from the phase separator as a light mixed refrigerant stream and whereby the condensed fraction is discharged from the phase separator as a heavy mixed refrigerant stream.

7. The method according to claim 6, further comprising
- calculating a nitrogen target value using the real time optimization model, wherein the nitrogen target value corresponds to a relative amount of nitrogen in the light mixed refrigerant stream,

wherein said selectively feeding and/or bleeding comprises changing the relative amounts of nitrogen whereby decreasing a differential between an actual nitrogen content in the light mixed refrigerant stream and said nitrogen target value.

8. The method according to claim 6 or 7, further comprising:
- calculating a C3 target value using the real time optimization model, wherein the C3 target value corresponds to a relative amount of C3 in the heavy mixed refrigerant stream,

wherein said selectively feeding and/or bleeding comprises changing the relative amounts of C3 whereby decreasing a differential between an actual C3 content in the heavy mixed refrigerant stream and said C3 target value.

9. The method according to any one of claims 3 to 8, wherein the method further comprises passing the heavy mixed refrigerant stream to a first JT valve in the pressure reduction device and passing the light mixed refrigerant stream to a second JT valve in the pressure reduction device, wherein passing the heavy mixed refrigerant stream to the first JT valve comprises subcooling of the heavy mixed refrigerant stream in the cryogenic heat exchanger and passing the light mixed refrigerant stream to the second JT valve comprises condensing and subcooling of the light mixed refrigerant stream in the cryogenic heat exchanger, and wherein setting the first JT valve and the second JT valve in respective valve positions to impose a selected flow rate ratio between the heavy mixed refrigerant stream and the light mixed refrigerant stream, and wherein a composition ratio be-

tween the methane and C2 in the mixed refrigerant is regulated to accommodate to the selected flow rate ratio being imposed.

10. The method according to any one of the preceding claims, wherein said quality of the vaporous refrigerant is determined using a quality measurement instrument probing the vaporous refrigerant. 5
11. The method according to any one of the preceding claims, wherein the real time optimization model is a non-linear steady-state model. 10
12. A system for producing a cooled hydrocarbon stream, comprising: 15
 - a mixed refrigerant circuit filled with an inventory of a mixed refrigerant, said mixed refrigerant consisting of a mixture of at least two different components, said mixed refrigerant circuit comprising, when considered in a single pass in consecutive order, a suction drum, a compressor train in fluid connection with the suction drum and downstream of the suction drum, a condenser in fluid connection with the compressor train and downstream of the compressor train, a pressure-reduction device in fluid communication with the condenser and downstream of the condenser, and a cryogenic heat exchanger in fluid communication with the pressure-reduction device and downstream of the pressure-reduction device in which cryogenic heat exchanger the mixed refrigerant is allowed to evaporate, whereby the cryogenic heat exchanger discharges into the suction drum thereby completing said single pass, wherein the compressor train forms a first boundary between a low-pressure side and a high-pressure side of the mixed refrigerant circuit and wherein the pressure-reduction device forms a second boundary between the high-pressure side and the low-pressure side; 20
 - a hydrocarbon stream conduit in said cryogenic heat exchanger in indirect heat exchanging contact with the evaporating refrigerant, for cooling the hydrocarbon stream whereby heat passes from the hydrocarbon stream to the evaporating refrigerant, thereby forming the cooled hydrocarbon stream; 25
 - a driver for mechanically driving the compressor train at a power load; 30
 - a rundown line in fluid communication with the hydrocarbon stream conduit for discharging the cooled hydrocarbon stream from the cryogenic heat exchanger at a discharge temperature; 35
 - a discharge temperature sensor on the rundown line for measuring the discharge temperature; 40

- a quality measurement instrument to determine the quality of the vaporous refrigerant;
- a control unit comprising a real time optimizer that is arranged to calculate a pressure target value for the pressure in a selected point in the mixed refrigerant circuit using a real time optimization model based on a plurality of measured variables including temperatures and pressures in various locations in the mixed refrigerant circuit and the hydrocarbon stream conduit and quality of the vaporous refrigerant, while keeping the power load below a pre-determined maximum power load and while keeping the discharge temperature below a pre-determined maximum discharge temperature;
- a makeup line for selectively feeding at least one makeup stream of one of said components to and a bleed line for bleeding at least one bleed stream of refrigerant from the mixed refrigerant circuit whereby decreasing a differential between an actual pressure in said selected point and said pressure target value. 45

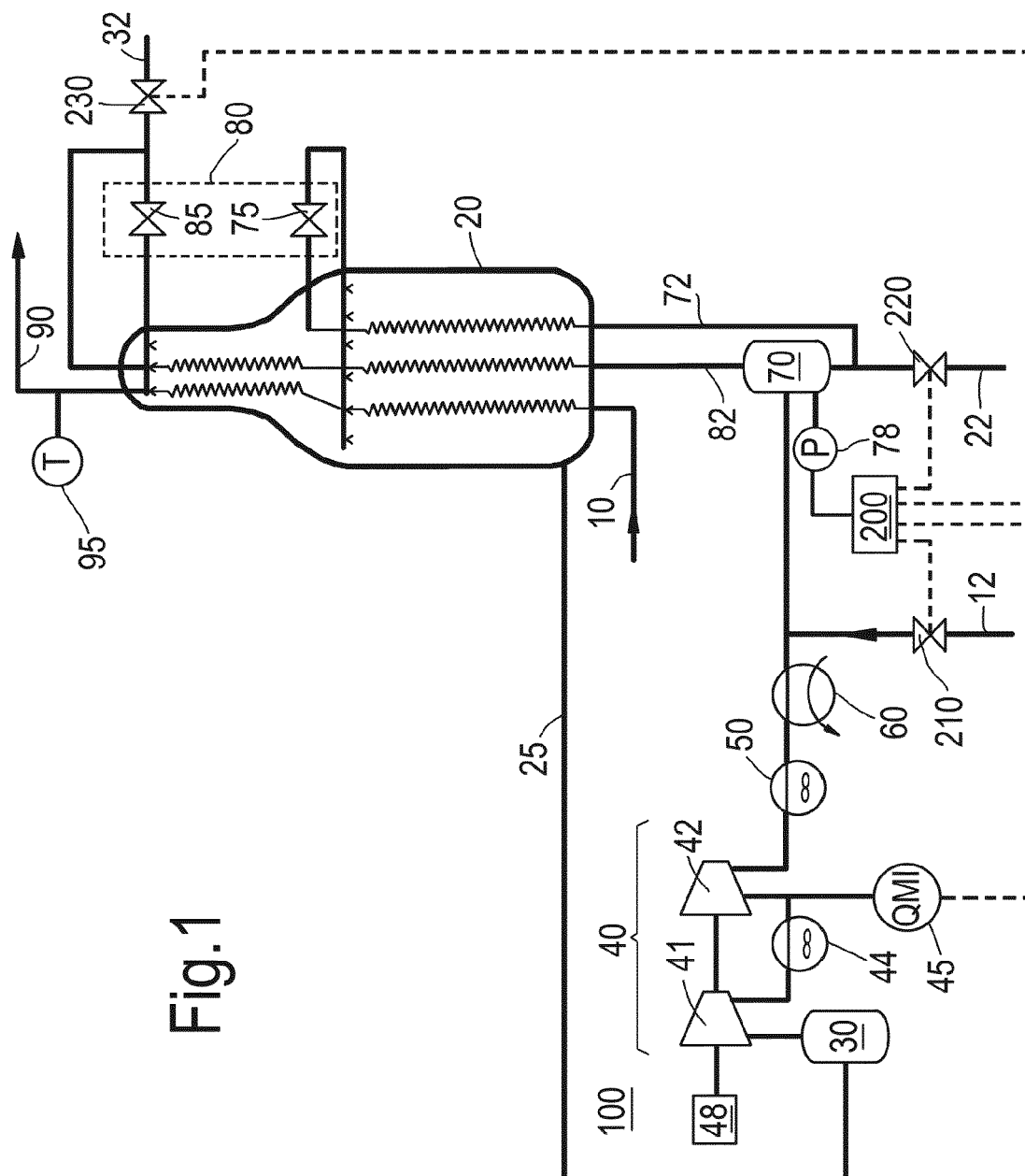


Fig. 1



EUROPEAN SEARCH REPORT

Application Number
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Munich		22 May 2015	Schopfer, Georg
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