A method and apparatus for liquefying a hydrocarbon stream (10) such as natural gas. The method comprises the steps of: (a) compressing the hydrocarbon stream (10) using one or more compressors (12) driven by one or more steam turbines (14) to provide a compressed hydrocarbon stream (20); (b) heat exchanging the compressed hydrocarbon stream (20) against one or more refrigerant streams (40) to fully condense the compressed hydrocarbon stream (20) and provide a liquefied hydrocarbon stream (30) and one or more warmed refrigerant streams (25); (c) compressing at least one of the warmed refrigerant stream(s) (50) of step (b) using one or more compressors (18) driven by one or more gas turbines (22); and (d) at least partly driving one or more of the steam turbines (14) of step (a) using steam provided by one or more of the gas turbines (22) of step (c).
METHOD AND APPARATUS FOR LIQUEFYING A HYDROCARBON STREAM

[0001] The present invention relates to a method and apparatus for liquefying a hydrocarbon feed stream, such as a natural gas feed stream.

[0002] Several methods of liquefying a natural gas feed stream thereby obtaining liquefied natural gas (LNG) are known. It is desirable to liquefy a natural gas stream for a number of reasons. As an example, natural gas can be stored and transported over long distances more readily as a liquid than in gaseous form, because it occupies a smaller volume and does not need to be stored at a high pressure.

[0003] Usually natural gas, comprising predominantly methane, enters an LNG plant at elevated pressures and is pre-treated to produce a purified feed stock suitable for liquefaction at cryogenic temperatures. The purified gas is processed through a plurality of cooling stages using heat exchangers to progressively reduce its temperature until liquefaction is achieved. The liquid natural gas is then further cooled and expanded through one or more expansion stages to final atmospheric pressure suitable for storage and transportation. The flashed vapour from each expansion stage can be used as a source of plant fuel gas.

[0004] The costs in creating and running a liquefied natural gas (LNG) plant or system are naturally high, and a significant part is for the cooling configurations. Any reduction in the energy requirements of the plant or system has significant cost benefit. Reducing any cost of any cooling configuration is particularly advantageous.

[0005] The use of steam turbines for driving compressors for refrigerants is known.

[0006] U.S. Pat. No. 6,389,844 B1 relates to a plant for liquefying natural gas, more specifically, a pre-cooled dual heat exchanger, dual refrigerant system. The plant in U.S. Pat. No. 6,389,844 B1 has a liquefaction capacity which is 40 to 60% higher than that of a single liquefaction train, and comprises one pre-cooling heat exchanger, and at least two main heat exchangers. Each liquefaction refrigerant circuit uses a gas turbine-driven liquefaction refrigerant compressor, and the driver of the compressor in the pre-cooling refrigerant circuit can be a steam turbine, wherein the steam required to drive the steam turbine can be generated with heat released from the cooling of the exhausts of the gas turbines of the main refrigerant circuits.

[0007] A drawback of driving a compressor in a refrigerant cycle like in U.S. Pat. No. 6,389,844, is that variations in the amount of steam generated by the cooling of the exhaust of the gas turbines could cause changes in refrigeration capacity of the refrigerant cycle.

[0008] The present invention provides a method of liquefying a hydrocarbon feed stream, such as a natural gas feed stream. The method at least comprises the steps of:

[0009] heat exchanging a compressed hydrocarbon stream against one or more refrigerant streams to fully condense the compressed hydrocarbon stream and provide a liquefied hydrocarbon stream and one or more warmed refrigerant streams;

[0010] compressing at least one of said one or more warmed refrigerant stream(s) using one or more refrigerant compressors driven by one or more gas turbines;

[0011] driving one or more compressor-driving steam turbines, at least partly using steam provided by at least one of said one or more gas turbines; and

[0012] providing said compressed hydrocarbon stream by compressing a hydrocarbon feed stream using at least one or more hydrocarbon feed compressors driven by said one or more compressor-driving steam turbines.

[0013] Advantageously, said liquefied hydrocarbon stream flows at a rate that is less than or equal to the flow rate of the hydrocarbon feed stream being compressed with said one or more feed compressors.

[0014] Advantageously, the one or more feed compressors are not incorporated in a refrigerant cycle.

[0015] In a further aspect, the present invention provides an apparatus for liquefying a hydrocarbon feed stream, such as a natural gas feed stream, the apparatus comprising:

[0016] a liquefying system arranged to receive a compressed hydrocarbon stream, the liquefying system comprising one or more cooling stages involving one or more refrigerant streams, through which cooling stage(s) the compressed hydrocarbon stream passes to provide one or more warmed refrigerant streams and a liquefied hydrocarbon stream;

[0017] one or more refrigerant compressors driven by one or more gas turbines to compress at least one of the warmed refrigerant streams;

[0018] one or more compressors driven by one or more compressor-driving steam turbines; and

[0019] one or more heat exchangers and one or more water/steam streams to transfer heat provided by the one or more gas turbines to at least partly drive one or more of the compressor-driving steam turbines,

[0020] wherein the one or more compressors driven by the one or more compressor-driving steam turbines are hydrocarbon feed compressor(s) arranged to receive and compress a hydrocarbon feed stream to provide the compressed hydrocarbon stream.

[0021] Advantageously, the liquefaction system is lined-up downstream of the one or more feed compressors and such that the liquefied hydrocarbon stream is provided at a flow rate that is less than or equal to the flow rate of the hydrocarbon feed stream passing through the feed compressor(s).

[0022] The present invention will now be further illustrated by way of example only, and with reference to embodiments and the accompanying non-limiting schematic drawings in which:

[0023] FIG. 1 is a generalised scheme of part of a liquefaction plant according to one embodiment of the present invention; and

[0024] FIG. 2 is a more detailed scheme of a liquefaction plant based on that in FIG. 1.

[0025] 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.

[0026] It is an object of the present invention to improve the efficiency of a plant or method for liquefying a hydrocarbon stream.

[0027] It is a further object of the present invention to reduce the energy requirements of a plant or method for liquefying a hydrocarbon stream.

[0028] The present invention is based on the insight that, of the various compressors that are typically present in a hydrocarbon liquefaction plant and process, the hydrocarbon feed compressors, which are arranged to compress the feed stream before liquefaction, are particularly suitable for being driven by the steam that is generated using heat of one or more gas turbines driving one or more refrigerant compressors in a refrigerant cycle in the liquefaction process.

[0029] In balancing the output/load of the refrigerant compressor(s), the steam production from the waste heat could at instances be less than usual. When using the steam to drive a hydrocarbon feed compressor, what then happens is that the
pressure at which the hydrocarbon stream is being liquefied may sometimes be lower than usual. This, however, has a relatively minor impact on the liquefaction process and on the distribution of cooling duty over the cooling stages compared to what would have been the case if the steam drives one or more refrigerant compressors.

Due to the relatively minor impact, there is provided more flexibility in operating the refrigerant compressor(s) that are driven by the gas turbines that provide the steam.

Because the power required to further compress a hydrocarbon stream to be liquefied is not as high as that required to compress the refrigerant required for the liquefaction process, a surprising benefit of the present invention is that more variation in plant design using the gas turbine(s) (depending on their load) can be accommodated in driving the steam turbine(s). Thus, there is more flexibility in using, more preferably balancing, the load/output of the refrigerant compressor(s) than has hitherto been possible. This flexibility increases the overall efficiency of a cooling, optionally liquefaction, plant, and can therefore reduce the energy required.

The method of the present invention also provides the advantage of controlling the pressure under which the liquefaction takes place. Thus, the operator can choose optimal pressure of the compressed hydrocarbon stream to suit subsequent process conditions. In particular, as the one or more steam turbines are driven inside the actual liquefying process, the volume or flow of hydrocarbon stream to be compressed and liquefied can be increased compared to conventional liquefaction processes only involving one or more steam turbines in a refrigeration cycle or cycle that are driven by steam generated from waste heat of the gas turbines that drive the liquefaction process.

The method of the present invention further provides the advantage of reducing running costs, including fuel consumption, for compression of the hydrocarbon stream prior to its liquefaction.

It is noted that U.S. Pat. No. 6,691,531 also relates to a natural gas liquefaction system using gas turbines to drive compressors in a first refrigerant cycle, and recovering waste heat from its gas turbines to help power steam turbines to drive compressors in a sub-cooling refrigerant cycle. The refrigerant in this sub-cooling refrigerant cycle consists of streams that have been separated from the feed stream, such that these separated stream are not the feed steam. The feed steam, on the other hand, is compressed in an inlet compressor.

Steam turbines have not hitherto been used to help compress a hydrocarbon feed stream prior to its liquefaction so as to best manage or balance power in a liquefaction plant.

Moreover, by mixing refrigerant and product streams in the sub-cooling refrigerant cycle, the system of U.S. Pat. No. 6,691,531 cannot control pressure of each part or phase.

Said mixing in the system of U.S. Pat. No. 6,691,531, thus brings a problem that variations in steam provided to the stream turbines driving the sub-cooling refrigerant compressors may lead to back flow conditions of either the inlet compressor or the sub-cooling refrigerant compressors.

As a consequence of said mixing upstream of the liquefaction condenser, the combined streams are liquefied so that the mass flow rate of liquefied hydrocarbons upstream of the expansion valve and flash drum is necessarily higher than the mass flow rate of hydrocarbons being compressed in the sub-cooling refrigerant compressors.

In embodiments of the invention, on the other hand, the liquefaction system is lined-up with the one or more feed compressors such that the liquefied hydrocarbon stream, upstream of any pressure let down in a flash unit, is provided at a flow rate that is less than or equal to the flow rate of the hydrocarbon feed stream passing through the feed compressor(s).

Preferably, the compressed hydrocarbon stream after it has been compressed using at least one or more feed compressors driven by said one or more compressors driving steam turbines, is not mixed with any compressed stream that has not been compressed with the at least one or more feed compressors driven by said one or more compressor-driving steam turbines.

A plant or method for liquefying a hydrocarbon stream such as natural gas may involve any number of gas turbines and steam turbines. For example, the heat exchanging of the compressed hydrocarbon stream against one or more refrigerant streams may involve at least 1-10 gas turbines, such as 2, 3, 4, 5, 6 or 7 gas turbines. One or more of such gas turbines may be used to compress refrigerant(s) in one or more refrigerant circuits for cooling a hydrocarbon stream, and one or more other gas turbines may be involved in one or more other parts, processes, steps or other functions in a plant or method designed to liquefy a hydrocarbon stream such as natural gas. Such other gas turbines may provide the power for other functions or processes such as electrical power regeneration, whilst providing some steam to help drive one or more steam turbines used in the present invention, or used elsewhere in a liquefied natural gas plant or method.

One or more of the compressors driven by steam turbines used in the present invention may also be partly driven by one or more alternative sources of power or energy.

The gas turbine(s) generally provide steam by heat transfer of their hot exhaust gases against a water line or a water and steam line, so as to increase the temperature of such a line to create steam at a desired pressure. Such steam may be used directly by a steam turbine, optionally dedicated steam turbine, or collected by or at a suitable unit, vessel, point or location, so as to provide management of its timing and distribution to one or more steam turbines as and when required, especially if there is variation of the load of the steam turbine(s).

One or more refrigerants of the refrigerant circuit may be a single component such as propane. Alternatively one or more refrigerants are mixed refrigerants based on two or more components, said components preferably selected from the group comprising nitrogen, methane, ethane, ethylene, propane, propylene, butanes and pentanes.

In one embodiment of the present invention, a hydrocarbon stream can be fully condensed and liquefied by passing it through at least two cooling stages. Any number of cooling stages can be used, and each cooling stage can involve one or more heat exchangers, as well as optionally one or more steps, levels or sections. Each cooling stage may involve two or more heat exchangers either in series, or in parallel, or in combination of same.

Arrangements of suitable heat exchangers able to cool and liquefy a hydrocarbon stream are known in the art, including for example U.S. Pat. No. 6,389,944 and U.S. Pat. No. 6,370,910.

In one arrangement, this involves the two cooling stages comprising a first cooling stage and a second cooling stage, the first stage being preferably a pre-cooling stage to cool the hydrocarbon stream to below 0° C., and the second stage preferably being a main cryogenic stage to liquefy the cooled hydrocarbon stream to below -100° C.

A hydrocarbon stream for use with the present invention may be any suitable hydrocarbon-containing 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 hydrocarbon stream may also be obtained from another source, also including a synthetic source such as a Fischer-Tropsch process.

Usually natural gas is comprised substantially of methane. Preferably the feed stream comprises at least 60 mol % methane, more preferably at least 80 mol % methane.

Depending on the source, the hydrocarbon stream may contain varying amounts of hydrocarbons heavier than methane such as ethane, propane, butanes and pentanes as well as some aromatic hydrocarbons. The hydrocarbon stream may also contain non-hydrocarbons such as H₂O, N₂, CO₂, H₂S and other sulfur compounds, and the like.

If desired, the hydrocarbon stream may be pre-treated before using it in the present invention. This pre-treatment may comprise removal of any undesired components present such as CO₂ and H₂S. As these steps are well known to the person skilled in the art, they are not further discussed here.

Further the person skilled in the art will readily understand that after liquefaction, the liquefied hydrocarbon 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 liquid turboexpander.

The present invention may involve one or more other or further refrigerant circuits, for example in or passing through a first cooling stage. Any other or further refrigerant circuits could optionally be connected with and/or concurrent with the refrigerant circuit for cooling the hydrocarbon stream.

FIG. 1 shows a general arrangement of part of a liquefied natural gas (LNG) plant 1. It shows an initial hydrocarbon stream 10 such as natural gas. In addition to methane, natural gas usually includes some heavier hydrocarbons and impurities, e.g. carbon dioxide, nitrogen, helium, water and non-hydrocarbon acid gases. The hydrocarbon stream 10 has usually been pre-treated to separate out these impurities as far as possible, and to provide a purified feed stream suitable for liquefying at cryogenic temperatures. The hydrocarbon stream 10 is typically at a temperature between -20°C and +80°C, and at a pressure between 50-60 bar.

The hydrocarbon stream 10 is compressed by a hydrocarbon feed compressor 12 in a manner known in the art. The hydrocarbon feed compressor 12 may comprise one or more compressors, usually in series. The hydrocarbon feed compressor 12 is driven by a steam turbine (“ST”) 14, and provides a compressed hydrocarbon stream 20.

The compressed hydrocarbon stream 20 passes through a liquefying system 16, which may comprise one or more cooling stages, and each stage may comprise one or more heat exchangers or other cooling units known in the art. Also passing through the liquefying system 16 is a refrigerant stream 40 adapted to provide cooling to the compressed hydrocarbon stream 20 in order to provide a liquefied hydrocarbon stream 30. From the liquefying system 16, a warmed refrigerant stream 50 is compressed by a refrigerant compressor 18 to provide a compressed refrigerant stream 60, which is then cooled in a manner known in the art, for example by passage through one or more water and/or air coolers, one of which coolers 24 is shown in FIG. 1.

The refrigerant compressor 18 may comprise one or more compressors, and is driven by a gas turbine (“GT”) 22. In use, a gas turbine 22 creates a gas turbine hot exhaust stream 70, which exhaust stream 70 can be passed through an exhaust heat exchanger 26. In the exhaust heat exchanger 26, heat from the exhaust stream 70 is transferred to a water/steam stream 80, such that the outflowing gas turbine exhaust stream 70a is cooled, and the water/steam stream 80 is heated to provide a heated steam stream 80a, which can then be conducted to the steam turbine 14 in a manner known in the art to help drive the hydrocarbon feed compressor 12.

Naturally, it is desired to improve the efficiency of the liquefied natural gas plant 1, and reduce the energy requirements where possible. However, the demand for the refrigerant compressor 18 can be required to be different due to expected variation in different process operations and parameters in different plant designs. This includes variation of the cooling duty of the refrigerant due to expected variation in the flow or load of the compressed hydrocarbon steam 20 to be cooled, and/or any operations of the liquefying system 16 not being optimal. Thus, there is variation in the design of the expected duty of the refrigerant compressor 18, which therefore alters the driving duty of the gas turbine 22, and therefore varies the creation and flow of the hot exhaust gas stream 70. Variation in the flow of the gas turbine exhaust stream 70 therefore impacts on the amount of expected steam in the stream 80a, able to power the steam turbine 14.

The presently disclosed apparatuses and methods provide more flexibility in using, more preferably balancing, the expected load of the refrigerant compressor 18, and thus the expected production of the gas turbine exhaust system 70, with the driving of the hydrocarbon feed compressor 12, than has hitherto been possible. This flexibility increases the design efficiency of the overall liquefaction plant 1, and can reduce the energy requirement expected.

It is known that a refrigerant compressor and a hydrocarbon feed compressor in a liquefied hydrocarbon plant do not sit in isolation, and are usually linked to other items, units or streams in the plant 1. Thus, where the gas turbine 22 may not provide a sufficient exhaust stream 70 to fully power the steam turbine 14, the power for the steam turbine 14 may also be provided from one or more other sources. Similarly, where the gas turbine 22 can provide a greater amount of exhaust stream 70 than is required to power the steam turbine 14, such excess steam or power can be used to help drive another unit and/or generate electricity in the plant 1.

However, usually, at least a majority of the power required to drive the steam turbine 14 is designed to be provided by the gas turbine exhaust stream 70, such that flexibility in any variation of the generation of gas turbine exhaust stream 70 is better accommodated by the steam turbine 14 driving a hydrocarbon feed compressor 12 rather than a refrigerant compressor.

FIG. 2 shows a more detailed scheme of a liquefied natural gas plant based on that shown in FIG. 1. In FIG. 2, a hydrocarbon stream 10 such as natural gas firstly passes into a pre-treatment stage 32. The pre-treatment stage 32 may comprise one or more units adapted to reduce, preferably minimise, non-hydrocarbons from the hydrocarbon stream 10. A typical such unit is an “acid gas removal” unit, used to reduce levels of carbon dioxide and hydrogen sulphide, and possibly other sulphur compounds.

The pre-treated hydrocarbon stream 10a therefrom is compressed in a hydrocarbon feed compressor 12, which is driven by a steam turbine 14. The compressed hydrocarbon stream 20 may be cooled by a water and/or air cooler 34, prior to passage through a liquefying system (such as the liquefying system 16 shown in FIG. 1) comprising a first cooling stage 2 and a second cooling stage 4.

The first cooling stage 2 involves a first heat exchanger 36 to provide a cooled hydrocarbon stream 100.
The first cooling stage 2 may comprise one or more heat exchangers, either in parallel, series or both. Typically, the first cooling stage 2 will cool the hydrocarbon stream to a temperature below 0°C, and preferably between -20°C and -60°C.

[0065] The cooled hydrocarbon stream 100 is then divided by a stream splitter 37 in a manner known to the art, to provide first and second cooled streams 100a, 100b. The cooled hydrocarbon stream 100 could be divided into any number of streams, and FIG. 2 shows the division into two streams by way of example only. The division of the cooled hydrocarbon stream 100 could be based on any ratio of mass and/or volume and/or flow rate. The ratio may be based on the size or capacity of the subsequent parts of the liquefaction stages or systems or units, or due to other considerations. One example of the ratio is an equal division of the feed mass.

[0066] The first and second streams 100a, 100b pass through a second cooling stage 4 where they are liquefied by two separate liquefaction systems, each generally including at least one heat exchanger respectively, to provide separate liquefied streams 110a, 110b respectively. Liquefaction systems and process conditions for liquefaction are well known in the art, and are not described in further detail herein. In FIG. 2, the two liquefaction systems are represented by first and second main heat exchangers 38a and 38b.

[0067] Each of the main heat exchangers 38a, 38b in the second cooling stage 4 of the example shown in FIG. 2 uses a second refrigerant circuit. Each of these refrigerant circuits can use a second refrigerant stream (170a, 170b) with or without being formed of the same or a different second refrigerant. Preferably, each uses the same refrigerant, and more preferably the refrigerant is a mixed refrigerant as hereinbefore described. Generally, the first and second gas streams 100a, 100b are cooled by the second cooling stage 4 to a temperature of at least below -100°C.

[0068] Following use of the refrigerant of each refrigeration circuit in the main heat exchangers 38a, 38b, warmed refrigerant streams 150a, 150b are withdrawn from the main heat exchangers 38a, 38b, and compressed by respective second refrigerant stream compressors 56a, 56b, in the form of main refrigerant compressors, which are respectively driven by gas turbines 58a and 58b. The compressed refrigerant streams may be cooled by one or more water and/or air coolers 161a, 161b, to provide cooled refrigerant streams 160a and 160b, which can be further cooled by passage through two refrigerant heat exchangers 62a and 62b to provide further cooled refrigerant streams 170a, 170b ready for reintroduction into the first and second main heat exchangers 38a, 38b.

[0069] Hot exhaust gases from the gas turbines 58a and 58b create two exhaust streams 190a and 190b, which pass into secondary heat exchangers in the form of exhaust heat exchangers 76a and 76b so as to transfer their heat to water/steam streams passing into the exhaust heat exchangers 76a and 76b, to provide heated steam streams 200a and 200b. These streams into a high pressure ("H P") collection point 78, which may be a simple connection of lines or conduits, or a reservoir or accumulator. The HP collection point 78 can provide an outflow steam stream 210a, which can power the steam turbine 14 in a manner described hereinabove.

[0070] With respect to the two liquefied hydrocarbon streams 110a and 110b from the main heat exchangers 38a, 38b, these can be combined by a suitable combiner 39 to create a combined liquefied stream 110c, which enters a gas/liquid separator such as in an end flash unit. An end flash unit typically comprises an expansion means (not shown), such as an expansion valve (not shown) and/or an expander turbine (not shown), followed by an end flash separation vessel 42. Alternatively it is possible to expand each of the liquefied hydrocarbon streams 110a and 110b before combining them in combiner 39.

[0071] The end flash unit can generally provide a liquefied hydrocarbon stream 120 and a gaseous steam 130. The liquefied hydrocarbon stream 120, which may typically be removed from the bottom of the end flash separation vessel 42, can be transported via a pump 44 to storage and/or transportation. The gaseous steam 130, which may typically be removed from the top of the end flash separation vessel 42, may be compressed in an end flash gas compressor 48, which may be driven by a steam turbine 52. The gaseous stream 130 may provide cooling energy through a heat exchanger 46, prior to being compressed. The compressed end stream 140 can then be further cooled by a water and/or air cooler 54 and withdrawn from the process for subsequent use.

[0072] In one embodiment of the present invention, power for the steam turbine 52 driving the end flash gas compressor 48 can also be supplied by steam provided by the gas turbines 58a and 58b for the main refrigerant compressors 56a, 56b. This is shown by steam stream 210 in FIG. 2, as auxiliarily provided by the HP collection point 78.

[0073] Cooling for the heat exchanger(s) in the first cooling stage 36 and for the second refrigerant heat exchangers 62a and 62b may be provided by a separate refrigerant circuit 6 in which a first refrigerant stream 180 is cycled. Refrigerant for the separate refrigerant circuit 6 may be a single component such as essentially consisting of propane, or a mixed refrigerant as hereinbefore described. The refrigerant can be provided from an accumulator 66, which refrigerant stream 180 is made up of separate steams 180a, 180b and 180c, which pass through the heat exchangers listed above, prior to their collection as warm refrigerant streams in a collector 68, for instance in the form of a collector drum or a collecting knock-out drum. From the collector 68, the collected streams are compressed by a, separate, first refrigerant stream compressor 72, which can be driven by a third gas turbine 74.

[0074] Similar to the actions of the gas turbines 58a and 58b described above, hot exhaust gases from the third gas turbine 74 may be passed as an exhaust stream 190 into a secondary heat exchanger 76c, to transfer heat to a water/steam stream so as to provide a third heated steam stream 200c, which may be passed to the HP collection point 78 to assist contribution of the driving of the steam turbines 14 and 52 as described above.

[0075] Thus, the arrangement shown in FIG. 2 has (at least) three gas turbines 74, 58a and 58b able to provide steam to help drive the steam turbines 14 and 52. There is significant flexibility in the use of the steam provided by the gas turbines 74, 58a, 58b, particularly using a collection point 78 which allows management and distribution of the steam in the most efficient or effective manner to the steam turbines 14 and 52. For example, it may be that one or both steam turbines 14, 52 may not require to be partly or fully driven at a particular time, such that power re-arrangement or re-configuration is easily achievable in the arrangement shown in FIG. 2. Any excess steam not required by the steam turbines 14, 52 could be used (via line 240) to provide power to other units or generators in the liquefied hydrocarbon plant 2.

[0076] The arrangement shown in FIG. 2 is also able to consider separation of the steam (indirectly) provided from each of the three gas turbines 74, 58a and 58b, such that only one or two of such gas turbines are providing steam which is
useable by the steam turbine 14. For example, it is possible for the gas turbine 74 to be the sole provider of steam for use in driving the steam turbine 14.

[0077] Thus, the present invention has further flexibility in considering different design arrangements for its gas turbines to provide steam for use in driving the steam turbine 14. For example, the arrangement shown in FIG. 2 may include one or more further gas turbines in the liquefied natural gas plant 12 (to drive other processes or functions) which may also provide steam for use in at least partly driving the steam turbine 14.

[0078] In a further embodiment of the present invention,

[0079] FIG. 2 shows use of steam created by the steam turbine 14 to provide an exhaust steam stream 220, which can be collected at a low pressure ("LP") collection point 82, which point 82 may involve an accumulator or collector. From the LP collection point 82, generally at low pressure, steam in line 230 can be used to provide heat to regenerate a substance or material used in the pre-treatment unit 32 in a manner known in the art, e.g., an amine liquid used for the absorption of acid gas. The low pressure collection point may also be a medium pressure ("MP") collection point if there exists a further low pressure collection point. Likewise, there may be an optional MP collection point upstream of the present LP collection point.

[0080] Another example of the application of LP (or MP) steam is to provide reboiler heat in a fractionation unit that may be present in a liquefaction plant. Thus, further efficiency is achieved in the liquefied natural gas plant by the use of steam in the exhaust gas rather than external power sources. There may be other suitable uses for the LP (MP) steam 230 as well.

[0081] 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.

1. A method of liquefying a hydrocarbon feed stream, the method at least comprising the steps of:
   - heat exchanging a compressed hydrocarbon stream against one or more refrigerant streams to fully condense the compressed hydrocarbon stream and provide a liquefied hydrocarbon stream and one or more warmed refrigerant streams;
   - compressing at least one of said one or more warmed refrigerant stream(s) using one or more refrigerant compressors driven by one or more gas turbines;
   - driving one or more compressor-driving steam turbines, at least partly using steam provided by at least one of said one or more gas turbines; and
   - providing said compressed hydrocarbon stream by compressing a hydrocarbon feed stream using at least one or more feed compressors driven by said one or more compressor-driving steam turbines.

2. A method as claimed in claim 1, wherein the heat exchanging of the compressed hydrocarbon stream against the one or more refrigerant streams involves any number of one to ten gas turbines.

3. A method as claimed in claim 1, wherein the heat exchanging of the compressed hydrocarbon stream against the one or more refrigerant streams involves at least two cooling stages.

4. A method as claimed in claim 3, wherein at least two cooling stages comprise:
   - a first cooling stage adapted to cool the hydrocarbon stream to form a cooled hydrocarbon stream at a temperature below 0°C against at least one first refrigerant stream, which first refrigerant stream is compressed by a first refrigerant stream compressor driven by at least one gas turbine; and
   - a second cooling stage adapted to liquefy the cooled hydrocarbon stream from the first cooling stage.

5. A method as claimed in claim 4, wherein liquefaction of the cooled hydrocarbon stream in the second cooling stage is carried out by two or more parallel liquefaction systems, each of which involves at least one second refrigerant stream that is compressed by a second refrigerant stream compressor driven by a gas turbine.

6. A method as claimed in claim 5, wherein the refrigerant for each second refrigerant stream is a mixed refrigerant based on two or more components selected from the group comprising nitrogen, methane, ethane, ethylene, propane, propylene, butanes and pentanes.

7. A method as claimed in claim 4, wherein each gas turbine comprising a refrigerant stream provides steam for use in driving one or more of the compressor-driving steam turbines.

8. A method as claimed in claim 1, wherein said liquefied hydrocarbon stream flows at a rate that is less than or equal to the flow rate of the hydrocarbon feed stream being compressed with said one or more feed compressors.

9. A method as claimed in claim 1, wherein the compressed hydrocarbon stream after it has been compressed using the at least one or more feed compressors driven by said one or more compressor-driving steam turbines, is not mixed with any compressed stream that has not been compressed with the at least one or more feed compressors driven by said one or more compressor-driving steam turbines.

10. A method as claimed in claim 1, wherein exhaust steam provided by the one or more steam turbines at least partly provides heat for use in removal of acid gas components in the hydrocarbon feed stream prior to its compression.

11. Apparatus for liquefying a hydrocarbon feed stream, the apparatus at least comprising:
   - a liquefying system arranged to receive a compressed hydrocarbon stream, the liquefying system comprising one or more cooling stages involving one or more refrigerant streams, through which cooling stage(s) the compressed hydrocarbon stream passes to provide one or more warmed refrigerant streams and a liquefied hydrocarbon stream;
   - one or more refrigerant compressors driven by one or more gas turbines to compress at least one of the warmed refrigerant streams;
   - one or more compressors driven by one or more compressor-driving steam turbines; and
   - one or more heat exchangers and one or more water/steam streams to transfer heat provided by the one or more gas turbines to at least partly drive one or more of the compressor-driving steam turbines,
   - wherein the one or more compressors driven by the one or more compressor-driving steam turbines are hydrocarbon feed compressor(s) arranged to receive and compress a hydrocarbon feed stream to provide the compressed hydrocarbon stream.

12. A method as claimed in claim 2, wherein the heat exchanging of the compressed hydrocarbon stream against the one or more refrigerant streams involves at least two cooling stages.
13. A method as claimed in claim 12, wherein the at least two cooling stages comprise:
a first cooling stage adapted to cool the hydrocarbon stream to form a cooled hydrocarbon stream at a temperature below 0° C. against at least one first refrigerant stream, which first refrigerant stream is compressed by a first refrigerant stream compressor driven by at least one gas turbine; and
a second cooling stage adapted to liquefy the cooled hydrocarbon stream from the first cooling stage.

14. A method as claimed in claim 13, wherein liquefaction of the cooled hydrocarbon stream in the second cooling stage is carried out by two or more parallel liquefaction systems, each of which involves at least one second refrigerant stream that is compressed by a second refrigerant stream compressor driven by a gas turbine.

15. A method as claimed in claim 14, wherein the refrigerant for each second refrigerant stream is a mixed refrigerant based on two or more components selected from the group comprising nitrogen, methane, ethane, ethylene, propane, propylene, butanes and pentanes.

16. A method as claimed in claim 5, wherein each gas turbine compressing a refrigerant stream provides steam for use in driving one or more of the compressor-driving steam turbines.

17. A method as claimed in claim 6, wherein each gas turbine compressing a refrigerant stream provides steam for use in driving one or more of the compressor-driving steam turbines.

18. A method as claimed in claim 13, wherein each gas turbine compressing a refrigerant stream provides steam for use in driving one or more of the compressor-driving steam turbines.

19. A method as claimed in claim 14, wherein each gas turbine compressing a refrigerant stream provides steam for use in driving one or more of the compressor-driving steam turbines.

20. A method as claimed in claim 15, wherein each gas turbine compressing a refrigerant stream provides steam for use in driving one or more of the compressor-driving steam turbines.

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