



(11) **EP 1 936 307 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
25.06.2008 Bulletin 2008/26

(51) Int Cl.:
F25J 3/02^(2006.01) F25J 1/02^(2006.01)

(21) Application number: **06125775.4**

(22) Date of filing: **11.12.2006**

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IS IT LI LT LU LV MC NL PL PT RO SE SI SK TR
Designated Extension States:
AL BA HR MK RS

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(54) **Method and apparatus for cooling a hydrocarbon stream**

(57) A method of cooling a hydrocarbon stream such as natural gas, the method at least comprising the steps of:

- (a) separating a feed stream (10) into a gaseous stream (130) and a liquid stream (70);
- (b) compressing the gaseous stream (130) to provide a

compressed gaseous stream (150);

- (c) dividing the compressed gaseous stream (150) into at least a first stream (170) and a second stream (160);
- (d) cooling, preferably liquefying, the first stream (170) to provide a cooled hydrocarbon stream; and
- (e) removing the second stream (160).

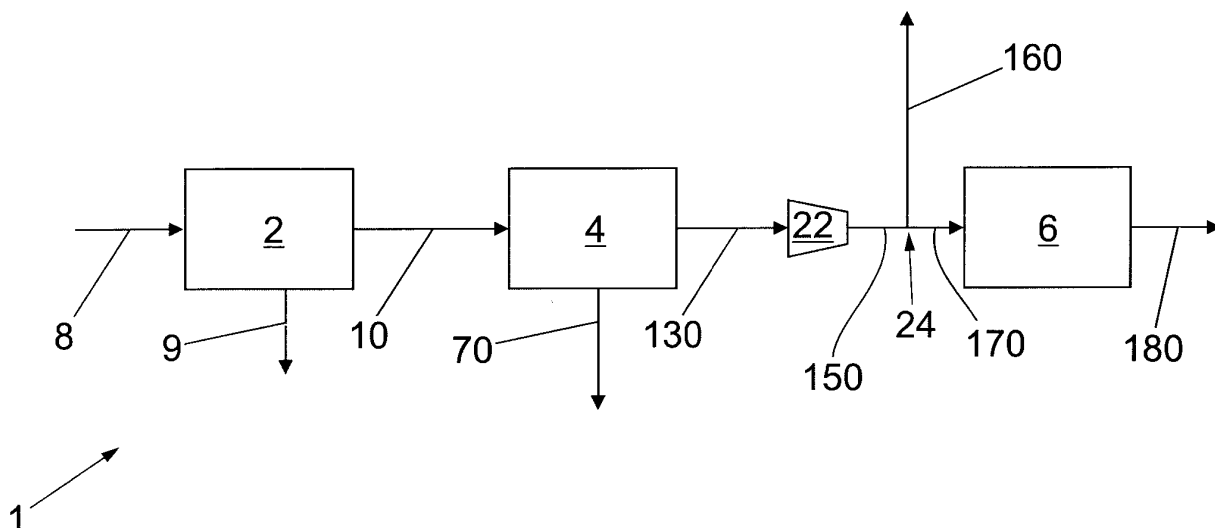


Fig. 1

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Description

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

[0002] Several methods of liquefying a natural gas 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 stream 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 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] US 2004/0079107 A1 shows a plant and process for the liquefaction of natural gas, whilst producing as a co-product a liquid stream consisting primarily of hydrocarbons heavier than methane such as natural gas liquids, liquefied petroleum gas (LPG) or condensate. The natural gas liquefaction plant shown in Figure 1 also produces another stream as fuel gas (stream 48). Such fuel gas is not compressed, and only for use in the plant.

[0005] Clearly the arrangement shown in US 2004/0079107 A1, and other similar arrangements, do not provide a stream that can be used outside the plant, especially without compression.

[0006] It is an object of the present invention to provide a plant or method for cooling a hydrocarbon stream, whilst at the same time providing a gas stream for use outside the plant or method.

[0007] It is another object of the present invention to provide a plant or method for cooling a hydrocarbon stream and providing a removable compressed gas stream with reduced capital and running costs.

[0008] One or more of the above or other objects can be achieved by the present invention providing a method of cooling a hydrocarbon stream such as natural gas, the method at least comprising the steps of:

- (a) separating a feed stream into a gaseous stream and a liquid stream;
- (b) compressing the gaseous stream to provide a compressed gaseous stream;
- (c) dividing the compressed gaseous stream into at least a first stream and a second stream;
- (d) cooling, preferably liquefying, the first stream to provide a cooled hydrocarbon stream; and
- (e) removing the second stream.

Thus, the second stream is provided as a compressed stream, which compressed stream can be used or provided as a high pressure stream. This reduces the capital and running costs required for separate compression of such a stream where it is desired to be at a high pressure. The second stream is immediately available at high pressure, for example for direct passage, possibly over some distance, to a suitable user.

The term "high pressure" as used herein relates to a stream having a pressure of >45 bar, preferably >50, >60, >70, >80 or even greater than 90 bar, generally measured or referenced at, just after, or shortly after the division of the compressed gaseous stream in step (c). This is in contrast to a "low pressure" stream, which could be in the range 20-30 bar.

Because the second stream provided by step (c) is already pressurised, and does not need any separate compression or compression step for use as a high pressure stream, it could be used for example as domestic gas.

Domestic gas is a fuel stream which is useable in or at a separate location, usually remote from the apparatus, plant or facility providing the method of the present invention. Thus, the second stream is 'removed' therefrom.

In one example, the second stream is removed to a gas grid or gas network, for example one supplying industrial and/or domestic consumers with gas for burning in relevant plants or appliances such as power stations or hot water boilers.

In another example, the second stream is removed by passage for at least 3 km, usually by at least 5 km, away from the plant or method providing the method of the present invention. For example, where the present invention is part of a liquefied natural gas plant or facility, the second stream could be piped away by 3 or 5 km at least to a grid, network, or other direct use situation.

Thus, the second stream is available as a direct product stream by remote users, and the present invention provides a method and plant able to provide a high pressure methane-enriched stream which is directly useable as for example domestic gas. This stream is provided as an easily available stream without requiring a separate compression step. Compression, with its attendant equipment and energy requirement, may otherwise make any such stream uneconomical or inefficient to provide.

Where the feed stream is natural gas, the second stream provided by step (c) can be >90 mol% methane, usually >95 mol% methane. The majority of the remainder of such a stream is usually ethane. Preferably, the second stream comprises less than 0.1 mol% C₅+ hydrocarbons.

Preferably, the temperature of the second stream is at least ambient, preferably greater than ambient. This is in contrast to any cooled stream that may be provided as a co-product stream from a liquefaction plant, but whose cold energy may be otherwise wasted.

A feed stream for use with the present invention may be any suitable hydrocarbon-containing gas stream to be cooled, 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.

Although the method according to the present invention is applicable to various hydrocarbon feed streams, it is particularly suitable for natural gas streams to be liquefied. As the person skilled readily understands how to liquefy a hydrocarbon stream, this is not further discussed here. The present invention is not limited to a method liquefying a hydrocarbon stream.

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

Optionally, a part or fraction of the second stream of step (c), and/or any further stream provided by step (c), could be used in the apparatus, plant or facility providing the method of the present invention, for example as a fuel gas. Use of the part of the second stream, (or the provision of any third, fourth, etc. stream in step (c)) in the apparatus, plant or facility may depend upon demand for the second stream outside the apparatus, plant or facility.

The compressed gaseous stream of step (b) may be divided into a first stream and a second stream (and any further streams) based on any ratio of mass, molecular weight or volume. The ratio may depend upon the demand for the first stream, second stream or both streams. Usually, a cooling system, such as a liquefying system, requires a minimum pre-determined mass or volume of a hydrocarbon stream so as to be efficient, which requirement may then determine the amount of second stream able to be provided.

In one embodiment of the present invention, the second stream comprises between 10 to 40 wt% of the compressed gaseous stream of step (b).

The gaseous stream provided by step (a) may be compressed using any compressor or compressors known in the art. This can include two or more compressors in series.

The compressed gaseous stream of step (b) may be cooled prior to step (c) by any means or method known in the art. This includes the use of one or more heat exchangers, such as water and/or air coolers, known in the art.

The feed stream of step (a) may be separated into a gaseous stream and a liquid stream by any gas/liquid separator known in art, which may involve one or more separators, refluxes, recycles, etc.

Preferably, the feed stream of step (a) is separated using a natural gas liquids (NGL) extraction unit. NGL extraction units are known to those skilled in the art. Generally, they are designed to reduce the level or levels of hydrocarbon compounds other than methane in a feed stream. One common NGL extraction unit includes a separator or separation vessel, able to provide a gaseous stream which is methane-enriched, and one or more other streams. Such other stream or streams usually but not always include separate or combined streams of heavier hydrocarbons.

In one example, an NGL extraction unit provides a liquid stream as a single heavier hydrocarbon rich stream, which is subsequently used either per se, or is further divided into particular heavier hydrocarbon rich streams in a separate location or unit. The division of a heavier hydrocarbon rich stream can also be carried out by one or more separators known in the art, such as a fractionator. A fractionator using one or more columns could provide individual streams of certain heavier hydrocarbons. For example, with multiple columns, each column could be designed to provide an individual hydrocarbon stream, such as an ethane-rich stream, a propane-rich stream, a butane-rich stream, and a C₅+ - rich stream (sometimes also termed a 'light condensate stream'). Propane, butane and C₅+ hydrocarbons are sometimes collectively termed "natural gas liquids" (NGL), and have known uses.

An example of a fractionation tower as a conventional distillation column for NGL extraction is shown in US 2004/0079107 A1.

In another example, an NGL extraction unit can include a fractionator which integrally provides individual streams of certain heavier hydrocarbons such as those listed hereinbefore.

Methods and apparatus for the cooling, preferably liquefying, a hydrocarbon stream in step (d) of the present invention are known in the art. They include the use of one or more cooling systems and/or one or more liquefying systems.

A cooling system may be a liquefying system. Cooling systems and liquefying systems may be embodied in various ways, and generally involve one or more heat exchangers and refrigerant circuits. Examples of suitable liquefying systems include those shown in US 6,389,844 B1 and EP 1 088 192 B1.

A liquefying system useable with the present invention may involve a number of separate serial cooling steps, and the or each cooling step may involve one or more heat exchangers, levels or sections. One arrangement involves the cooling stage having a first cooling step for pre-cooling, followed by a second cooling step for main cryogenic cooling and liquefying.

A first or pre-cooling step may involve reducing the temperature of a feed stream to below -0 °C, for example in the range -10 °C to -30 °C.

A second or main cryogenic cooling step may involve cooling a feed stream to below -90 °C or below -100 °C, for example between -100 °C to -130 °C, which usually creates a hydrocarbon stream which is now liquefied, such as liquefied natural gas.

The present invention includes a combination of any and all of the methods herein described.

Prior to step (a), the feed stream may pass through a gas treatment stage. In a gas treatment stage, the level or levels of certain impurities generally not being hydrocarbons can be reduced. Two common impurities are carbon dioxide and hydrogen sulphide (and any other sulphur-based compounds), usually present with water in the form of 'acid gas'. Many processes for the removal of acid gas from a feed stream are known to those skilled in the art. One common method is the use of an aqueous amine solution, often used in a unit termed a 'scrubber'. The aqueous amine may be one or more of known materials including for example DGA, DEA, MDEA, MEA and SULFINOLTM (Shell), and combinations thereof. Typically acid gas removal can result in the reduction of carbon dioxide to levels of less than about 60 ppm, whilst sulphur can be reduced to levels of less than about 4 ppm.

In a further aspect, the present invention provides apparatus for cooling a hydrocarbon stream such as natural gas from a feed stream, the apparatus at least comprising:

- (i) a gas/liquid separation stage to receive a feed stream and to provide a gaseous stream and a liquid stream;
- (ii) a compressor to compress the gaseous stream;
- (iii) a divider to divide the compressed gaseous stream into at least a first stream and a second stream;
- (iv) a cooling stage to receive the first stream, the cooling stage comprising one or more cooling systems to provide a cooled, preferably liquefied, hydrocarbon stream; and
- (v) a line to remove the second stream.

[0009] Embodiments of the present invention will now be described by way of example only, and with reference to the accompanying diagrammatic and non-limiting drawings in which:

Figure 1 is a block scheme of part of an LNG plant according to one embodiment of the present invention; and Figure 2 is a more detailed scheme of part of the LNG plant shown in Figure 1.

[0010] 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.

[0011] Figure 1 shows a block scheme of part of a liquefied natural gas plant 1. It shows an initial stream 8 containing natural gas, whose typical composition is shown in Table 1 hereinbelow.

[0012] The initial stream 8 passes to a gas treatment stage 2 comprising one or more gas treatment units. Such gas treatment units are adapted to reduce impurities, including but not limited to acid gas, in the initial stream 8, and so provide a treated feed stream 10, whose typical composition is also shown in Table 1 hereinafter. Operation of gas treatment units such as scrubbers are well known in the art. Figure 1 also shows an exit stream 9 for carbon dioxide, hydrogen sulphide, and any other sulphur-based compounds, from the gas treatment stage 2.

[0013] The treated feed stream 10 is passed to gas/liquid separation stage 4, such as an NGL extraction stage, which could comprise one or more NGL extraction units. The NGL extraction stage 4 provides a gaseous stream 130, which stream is methane-enriched, and a liquid stream, usually a heavier hydrocarbon enriched stream 70 which can pass to a common fractionator (not shown).

[0014] A common fractionator can be designed to provide separate enriched streams of one or more hydrocarbons such as propane, butane and C₅+ hydrocarbons, and optionally also ethane. Such enriched streams are useful products for use in the liquefying plant 1 or outside the plant. The fractionator may be a single fractionation unit, or have one or more columns, wherein each column is usually dedicated to separating and providing a particular heavier hydrocarbon. Fractionation is well known in the art and the benefit and use of individual streams of propane, butane and C₅+ are also well known in the art.

[0015] The gaseous stream 130 is compressed via compressor 22, which may comprise one or more compressors, to provide a compressed gaseous stream 150. The compressed gaseous stream 150 may then be cooled (not shown), prior to being divided by a divider 24 into a first stream 170 and a second stream 160. The division of the compressed gaseous stream 150 may be based on any ratio of mass, volume or molecular weight.

[0016] The second stream 160 is therefore at a high pressure, generally being greater than 45 bar, which is therefore directly removable, and useable as a fuel stream either wholly or partly outside the liquefied natural gas plant 1. One outside or remote use is as domestic gas, which can be used in industrial applications such as power generation, and/or

sent to a gas grid or network (represented as 56 in Figure 2) providing gas for domestic use and applications such as heating and cooking. This domestic gas stream does not need to be compressed by a separate compressor or other compression step for use as domestic gas.

[0017] Typical compositions for the initial stream 8, the treated feed stream 10, and the second stream 160, are shown in the following Table 1.

Table 1

Mol%	8	10	160
NITROGEN	3.44	3.35	3.47
H ₂ S	1.73	0.00	0.00
CO ₂	2.40	0.00	0.00
METHANE	83.31	87.69	90.74
ETHANE	5.38	5.60	5.75
PROPANE	2.12	2.00	0.04
IBUTANE	0.39	0.35	0.00
BUTANE	0.61	0.53	0.00
IPENTANE	0.19	0.16	0.00
PENTANE	0.17	0.14	0.00
HEXANE	0.01	0.09	0.00
C ₇ ⁺	0.24	0.10	0.00
Total	100.00	100.00	100.00

[0018] Meanwhile, in Figure 1, the first stream 170 is cooled in a cooling stage 6, which stage 6 may involve any degree of cooling using any number of units, devices or systems or combinations thereof known in the art. One example is the use of one or more heat exchangers. Usually, cooling is effected by passing the first stream 170 against one or more cooling or refrigerant streams and/or through one or more valves and/or separators, as known in the art.

[0019] In one embodiment of the present invention, the cooling stage 6 is adapted to liquefy the first stream 170 so as to provide a liquefied hydrocarbon stream 180 such as liquefied natural gas. Liquefaction of the first stream 170 can be carried out by passing it through a cooling system being a liquefying system using one or more heat exchangers and cooling it against one or more refrigerants, either being dedicated refrigerants or other cooled streams. The liquefying can involve one or more cooling and/or liquefying steps.

[0020] Generally, it is intended to provide a liquefied natural gas stream having a temperature below -150 °C, more usually between -160 °C and -165 °C.

[0021] Figure 2 shows a more detailed arrangement for one example of the gas/liquid separation stage 4 shown in Figure 1.

[0022] Figure 2 shows the treated feed stream 10 being cooled by passage through a first heat exchanger 32 to provide a cooled feed stream 20, which is passed to a first gas/liquid separator 34. The first gas/liquid separator 34 provides a first liquid stream 30 and a first gaseous stream 40 in a manner known in the art. Where the treated feed stream 10 is natural gas, the first gaseous stream 40 will usually be methane-enriched, optionally including a minor percentage of ethane, and the first liquid stream 30 is a heavier hydrocarbon rich stream.

[0023] The first liquid stream 30 passes through a valve 36 and into a second gas/liquid separator, an example of which is a deethanizer 38.

[0024] The first gaseous stream 40 is expanded by a first expander 42, and the expanded stream 50 provided thereby passes through a second heat exchanger 44 to provide an exit stream 60, which is passed into the deethanizer 38, preferably at or near the top of the deethanizer 38.

[0025] Deethanizers are known in the art, and one example is a fractionation tower acting as a distillation column having a number of vertically spaced trays. Generally, a deethanizer provides a C3+ stream from at or near its base, and a methane and ethane enriched stream from at or near its top.

[0026] In Figure 2, the deethanizer 38 provides a second gaseous stream 80 from the top thereof. The second gaseous stream 80 passes through the second heat exchanger 44. Preferably it passes countercurrently to the exit stream 50 from the first expander 42 so as to be cooled by the exit stream 50, and so as to provide a cooled second gaseous stream 90. This stream 90 passes into a second gas/liquid separator 46, which provides a second liquid stream 110 which can be recycled into the deethanizer 38 as a reflux stream in a manner known in the art, and a third gaseous stream 120. The third gaseous stream 120 passes through the first heat exchanger 32, usually in a countercurrent direction to the treated feed stream 10, so as to provide cooling to the treated feed stream 10. The warmed third gaseous

stream 130 from the first heat exchanger 32 is then compressed.

[0027] In Figure 2, the compression is provided by two compressors, 22a and 22b. The first compressor 22a can at least partly be driven by the first expander 42 to reduce the compression power otherwise required. Thus, the first expander 42 and the first compressor 22a may be mechanically interconnected, for example via a direct drive shaft 48, or by other connection mechanisms known in the art, optionally including one or more gears or gear mechanisms.

[0028] The first compressor 22a provides an intermediate compressed gaseous stream 140, and the second compressor 22b provides a final compressed gaseous stream 150. Following compression, the final compressed gaseous stream 150 may require cooling, and this could be provided by one or more heat exchangers. Figure 2 shows a water and/or air cooler 52, which may comprise one or more coolers or heat exchangers, so as to provide a cooled gaseous stream 155.

[0029] The cooled gaseous stream 155 is then divided by a divider 24 into a first stream 170 and a second stream 160. The cooled gaseous stream 155 may be divided in any known mass or ratio, but the present invention provides that the second stream 160 does not require a further compression step for its use as a fuel stream outside of the liquefied natural gas plant 1.

[0030] The second stream 160 is removed from the gas/liquid separation stage 4, and indeed from the liquefied natural gas plant 1, over a distance to a gas grid 56 as described hereinbefore.

[0031] Meanwhile, the deethanizer 38 provides a C₃+ enriched stream 190, which stream 190 passes into a third heat exchanger 54 and then into a third gas/liquid separator 56, which third gas/liquid separator 56 can provide a gaseous enriched stream 200 which can be recycled back into the deethanizer 38 in a manner known in the art, and a liquid stream 70, which can then be used as described hereinabove in relation to Figure 1.

[0032] The following Table 2 provides typical pressure, temperature and mass flow data for a working example of the present invention based on the arrangement shown in Figure 2.

Table 2

Stream number	Temperature (°C)	Pressure (bar)	Mass flow (kg/s)	Phase
10	21.0	65.7	233.0	Vapor
20	-48.0	64.7	233.0	Mixed
30	-48.1	64.6	27.4	Liquid
40	-48.1	64.6	205.5	Vapor
50	-83.0	28.5	205.5	Mixed
60	-75.1	28.1	205.5	Liquid
70	97.8	28.0	7.0	Liquid
80	-72.1	27.8	226.0	Vapor
110	-78.5	27.3	22.5	Liquid
120	-78.5	27.3	210.6	Vapor
130	19.0	26.6	210.6	Vapor
140	68.0	32.3	210.6	Vapor
150	174.4	93.4	207.5	Mixed
160	51.0	92.6	25.0	Vapor
170	51.0	92.6	182.5	Vapor

[0033] 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. A method of cooling a hydrocarbon stream such as natural gas, the method at least comprising the steps of:

- separating a feed stream (10) into a gaseous stream (130) and a liquid stream (70);
- compressing the gaseous stream (130) to provide a compressed gaseous stream (150);
- dividing the compressed gaseous stream (150) into at least a first stream (170) and a second stream (160);
- cooling, preferably liquefying, the first stream (170) to provide a cooled hydrocarbon stream; and

(e) removing the second stream (160).

2. A method as claimed in claim 1 wherein the second stream (160) comprises >90 mol%, preferably >95 mol%, methane.

3. A method as claimed in claim 1 or claim 2 wherein the compressed gaseous stream (150) is cooled prior to step (c).

4. A method as claimed in one or more of the preceding claims wherein the second stream (160) comprises between 10 to 40 wt% of the compressed gaseous stream (150).

5. A method as claimed in one or more of the preceding claims wherein the pressure of the second stream (160) is >45 bar, preferably >50, >60, >70, >80 or greater than 90 bar.

6. A method as claimed in one or more of the preceding claims wherein the temperature of the second stream (160) is at least ambient temperature, preferably greater than ambient temperature.

7. A method as claimed in one or more of the preceding claims wherein the second stream (160) is removed in step (c) to a gas grid (56) or gas network.

8. A method as claimed in one or more of the preceding claims wherein the second stream (160) is removed in step (c) by passage along a pipeline for at least 3km.

9. A method as claimed in one or more of the preceding claims wherein the second stream (160) comprises less than 0.1 mol% C₅+ hydrocarbons.

10. A method as claimed in one or more of the preceding claims wherein the liquid stream (70) is fractionated to provide one or more fractionated streams, preferably one or more of a propane stream, a butane stream, and a C₅+ stream.

11. A method as claimed in one or more of the preceding claims wherein the cooling step (d) liquefies the first stream (170) to provide a liquefied hydrocarbon stream (180), preferably liquefied natural gas.

12. Apparatus for cooling a hydrocarbon stream such as natural gas, the apparatus at least comprising:

(i) a gas/liquid separation stage (4) to receive a feed stream (10) and to provide a gaseous stream (130) and a liquid stream (70);

(ii) a compressor (22) to compress the gaseous stream (130);

(iii) a divider (24) to divide the compressed gaseous stream (150) into at least a first stream (170) and a second stream (160);

(iv) a cooling stage (6) to receive the first stream (170), the cooling stage (6) comprising one or more cooling systems to provide a cooled, preferably liquefied, hydrocarbon stream; and

(v) a line to remove the second stream (160).

13. Apparatus as claimed in claim 12 wherein the second stream (160) is domestic gas comprising >90 mol%, preferably >95 mol%, methane, <0.1 mol% C₅+ hydrocarbons, and having a pressure of >45 bar.

14. Apparatus as claimed in claim 12 or claim 13 for providing a liquefied hydrocarbon stream (180), preferably liquefied natural gas.

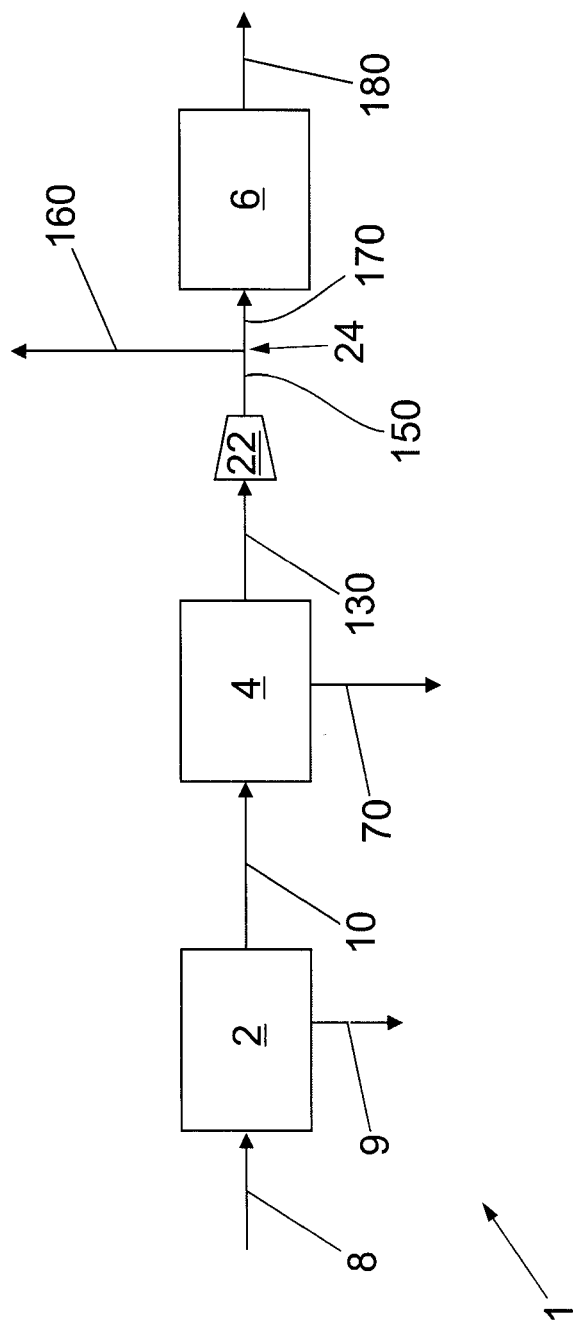


Fig. 1

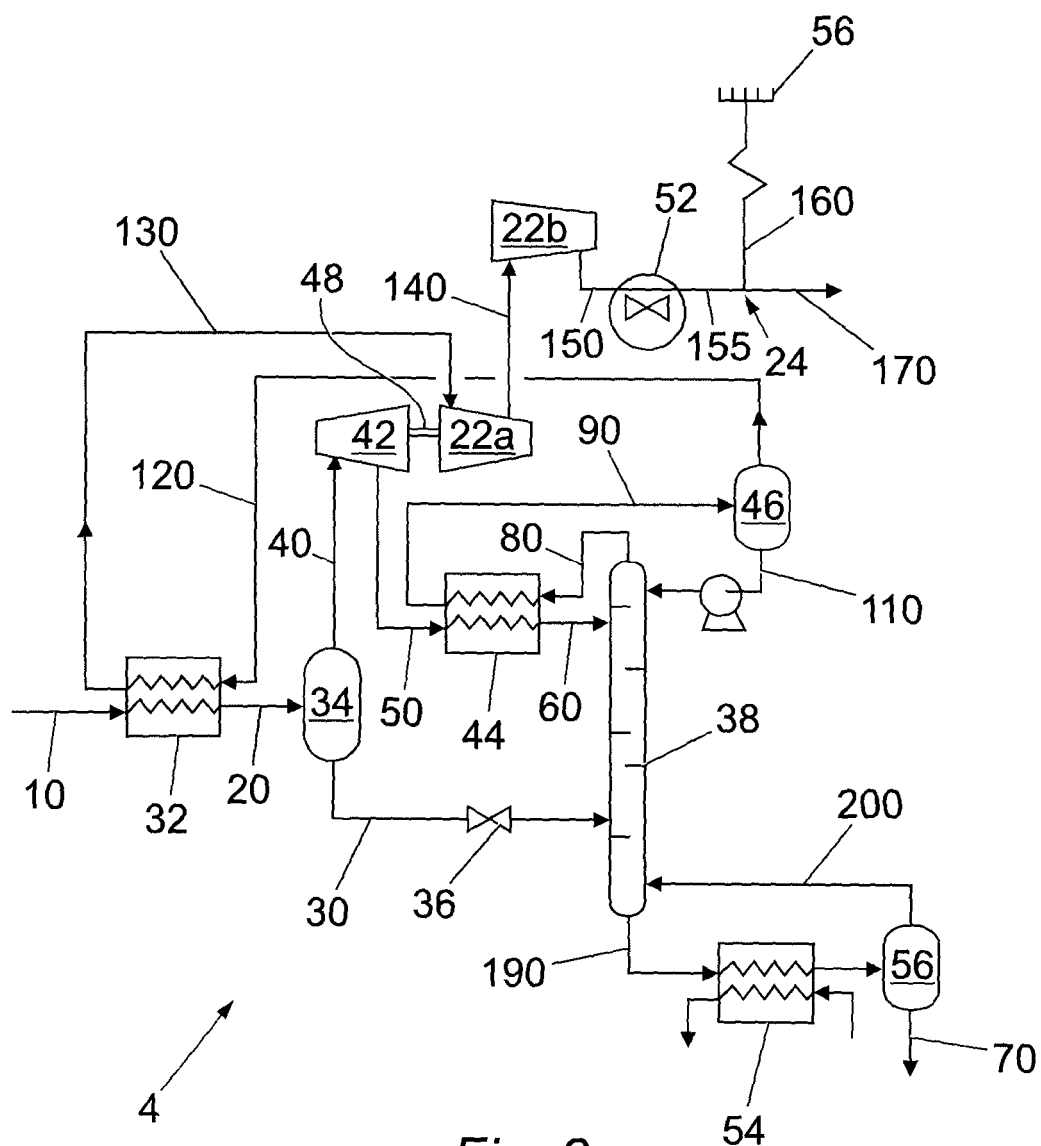


Fig. 2



European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 06 12 5775

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EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
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EP 06 12 5775

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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