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PROCESS AND APPARATUS FOR LIQUEFYING NATURAL GAS CONTAINING NITROGEN BY USING COOLED, EXPANDED AND FLASHED GAS THEREFROM AS A COOLANT THEREFOR

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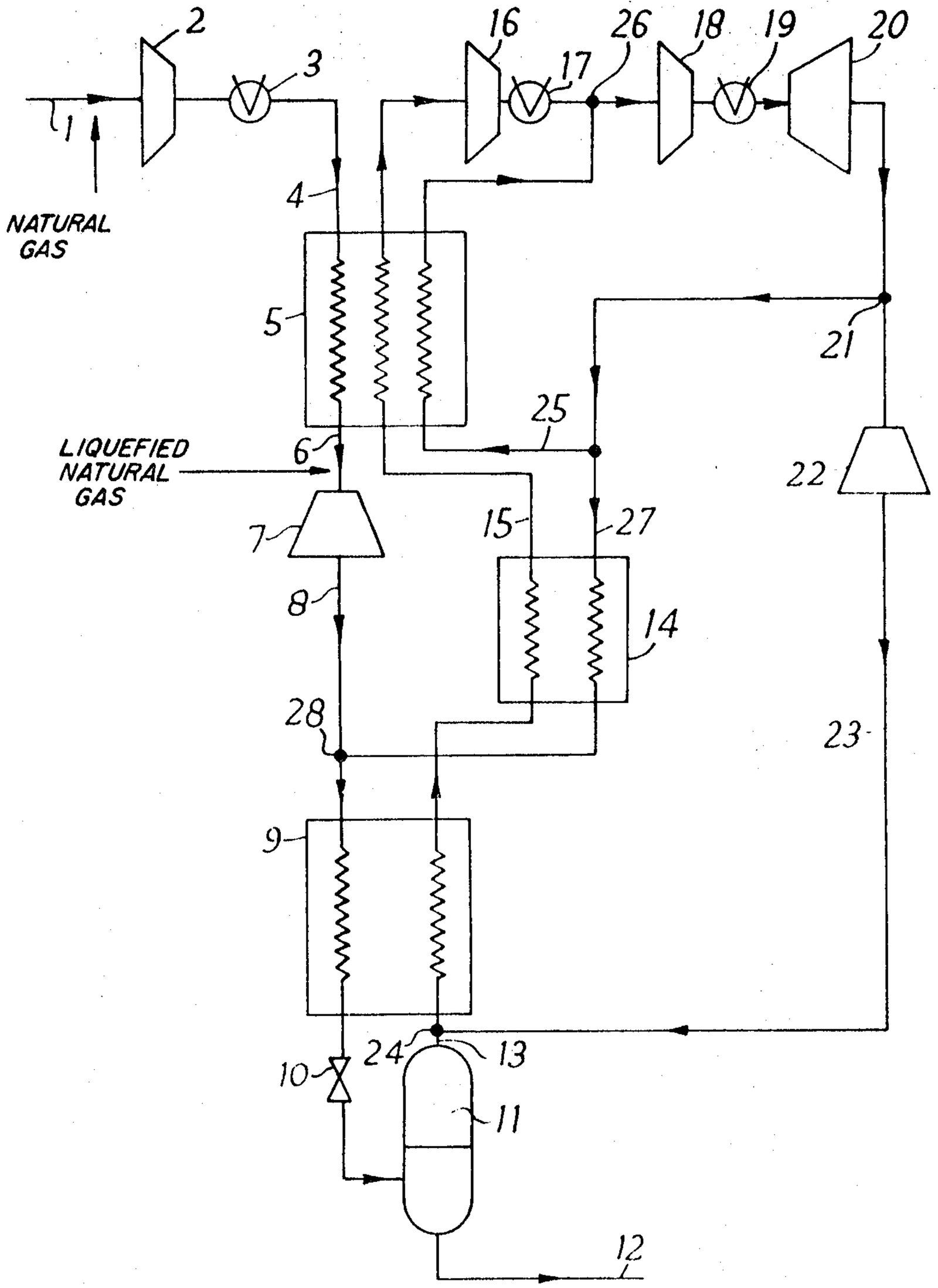

Inventor
Manfred otto Engel
By
Kenmon, Palmer, Stewart & Oslakrook
Attorneys

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PROCESS AND APPARATUS FOR LIQUEFYING NATURAL GAS CONTAINING NITROGEN BY USING COOLED, EXPANDED AND FLASHED GAS THEREFROM AS A COOLANT THEREFOR

Manfred O. Engel, Newcastle-upon-Tyne, England, assignor to Conch International Methane Limited, Nassau, The Bahamas

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ABSTRACT OF THE DISCLOSURE

A liquefaction process for natural gas in which the gas is initially liquefied at high pressure, the liquid is expanded and cooled and then flashed to give low pressure liquid and flash gas, and the flash gas is recirculated to cool the incoming gas at various stages of the process. The recirculated flash gas can be cooled by compression and expansion and re-introduced into the system at various points including that at which the liquid gas before flashing is present.

This invention relates to a process for liquefying natural gas.

According to the invention a process for liquefying natural gas comprises compressing raw natural gas in gaseous form to an upper pressure level, cooling and liquefying the gas at said upper pressure level, expanding the liquid thus formed to an intermediate pressure level, further cooling the liquid and flashing it to form a low pressure liquid and a flash gas, and re-circulating the flash gas in a separate circuit so as to assist in the cooling of the natural gas.

In the preferred embodiment the flash gas re-circulates in a separate low pressure circuit where it cools the raw natural gas by indirect heat exchange, is then compressed to the higher pressure level and then expanded to the intermediate pressure level. Part of the flash gas at the intermediate pressure level is further expanded to the lower pressure level and re-mixed with the low pressure flash gas. The remainder of the flash gas at the intermediate pressure level is divided into two streams, one stream is used to help liquefy the raw natural gas while it is still at the higher pressure level whilst the other stream is added to the raw natural gas after it has been liquefied and reduced to the intermediate pressure level.

The process of the present invention will now be described in one form by way of example with reference to the accompanying diagrammatic drawing.

Raw natural gas enters the plant through pine **1**, is compressed to an upper pressure level in compressor **2**, cooled in after-cooler **3** and then passes via pipe **4** to heat exchanger **5** where it is liquefied. The liquid passes through pipe **6** to expander **7** where it is expanded to an intermediate pressure level. The liquid at the intermediate pressure level then passes via pipe **8** to heat exchanger **9** where it is further cooled. It then passes to throttle valve **10** where it is expanded to a lower pressure level before entering flash vessel **11**.

Liquefied gas at the lower pressure level collects in the lower part of vessel **11** and flash gas collects over the liquid. The liquid is tapped off through pipe **12** and carried to storage vessels not shown.

The flash gas passes via pipe **13** through heat exchanger **9** thence through heat exchanger **14** and then via pipe **15** to heat exchanger **5**. On leaving heat exchanger **5** the flash gas passes to compressor **16** where it is raised to an intermediate pressure level, cooled in intercooler **17** compressed to the upper pressure level in compressor **18** cooled in intercooler **19** and then expanded to the intermediate pressure level again in expander **20**. On leaving expander **20** it passes to junction **21** where it is divided into two streams. One stream passes to expander **22** where it is expanded to the low pressure level and then passes via pipe **23** to junction **24** where it is mixed with flash gas leaving vessel **11**.

The other stream remains at the intermediate pressure level and is subdivided into two further streams one of which passes via pipe **25** through heat exchanger **5** and then rejoins the flash gas leaving intercooler **17** at junction **26**. The other stream passes via pipe **27** through heat exchanger **14** and that is introduced into the liquid natural gas at junction **28**.

The flash gas at the lower pressure level passing through pipe **23** acts as a low pressure refrigerant gas which assists the flash gas leaving vessel **11** to provide adequate cooling in heat exchangers **9** and **14**. The flash gas at the intermediate pressure level circulating through pipe **25** acts as an intermediate pressure refrigerant which assists in the cooling of the raw natural gas in heat exchanger **5**. The flash gas at the intermediate pressure level and passing through heat exchanger **14** to mix with the raw natural gas at junction **28**, also acts as an intermediate pressure refrigerant.

The re-introduction of flash gas at junction **28** maintains a mass balance in the circuit and as flash gas at the lower pressure level has a boiling point which is below the lowest cycle temperature it has to be compressed to the intermediate pressure before being returned at junction **28** so as to raise its boiling point to a level at which it can be liquefied in throttle **10**.

In a typical example, raw natural gas having the following composition by volume 83.7% methane, 7.9% ethane, 2.1% propane, 1% butane and higher hydrocarbons and 5.3% nitrogen was introduced to pipe **1**. For the purposes of the example it is assumed that any water, carbon dioxide or hydrogen sulphide in the natural gas has been removed by known processes.

The raw natural gas is compressed isothermally in compressor **2** to an upper pressure level of 200 atmospheres absolute, a pressure well above the critical pressure of the gas. In intercooler **3** the temperature of the gas is reduced to 300° K.

In heat exchanger **5** the gas is cooled to 170° K. which is well below the critical temperature of the gas at 200 atmospheres pressure. The gas is thus liquefied.

In expander **7** the liquid is expanded isentropically to the intermediate pressure level of 20 atmospheres absolute. In the process its temperature drops to 161° K. which is a few degrees below the bubble point at the intermediate pressure level.

The liquefied gas leaving the expander **7** is then mixed with the intermediate pressure refrigerant at **28**. The composition of the refrigerant by volume is 62.1% nitrogen and 37.9% methane producing a partially condensed vapour having the composition by volume 67.3% methane, 5.1% ethane, 1.3% propane, 0.7% butane and heavier hydrocarbons and 25.6% nitrogen.

The partially condensed vapour is further cooled to 122° K. in heat exchanger **9** and is then expanded isentropically in throttle **10** to a lower pressure level of 1.5 atmospheres absolute and a temperature of 107.4° K.

The fluid is then flashed in vessel **11** to form liquid natural gas at the lower pressure level. Of the total fluid entering vessel **11**, approximately 59% by volume is collected as liquid natural gas and the remainder appears as flash gas. The composition of the liquid natural

gas is the same as that of the raw gas entering pipe 1 whilst the composition of the flash gas, by volume, is 62.1% nitrogen, 37.9% methane.

The mixture of flash gas and the low pressure of refrigerant gas, which has the same composition, joining it at 24 passes through heat exchanger 9 where it is heated to 151° K. In heat exchanger 14 it is heated to 162° K. and finally in heat exchanger 5 to 290° K.

It then passes to compressor 16 where it is compressed to 20 atmospheres absolute then to intercooler 17 where it is cooled to 300° K. It is then mixed with intermediate pressure refrigerant at 26 and the mixture is then compressed to 200 atmospheres pressure absolute and subsequently cooled to 300° K. in after cooler 19. In expander 20 the mixture is expanded isentropically to 20 atmospheres absolute and to a temperature of 172° K. which is four degrees below the temperature of the liquid natural gas at the outlet of heat exchanger 5.

At junction 21, 35.4% by volume of the mixture is tapped off to form the intermediate pressure refrigerant. This is further sub-divided, 56.7% by volume passing through pipe 25 and the remainder through pipe 27. The gas passing through pipe 25 is heated to 290° K. in heat exchanger 5 while the gas passing through pipe 27 is partially condensed in heat exchanger 14 and leaves the heat exchanger with a temperature of 168° K.

The remaining 63.6% of the gas entering junction 21 is expanded in expander 22 to 1.5 atmospheres pressure absolute and a temperature of 107.4° K.

The supply of raw natural gas at the rate of 1.22×10^5 kilograms per hour would produce 1.22×10^5 kilograms per hour of liquefied natural gas of the same composition at 1.5 atmospheres pressure absolute. Gas boiling off from the liquid storage vessels and flash gas produced by expansion of the liquid leaving the vessel 11 to the pressure obtaining in the storage vessels, can be used as part of the fuel supply for prime movers driving the compressors.

The compressors and expanders used can be single or multistage as desired.

The above values are given by way of example only and natural gas of different composition can be liquefied by the same process. Likewise the values of pressures and temperatures quoted at various parts of the process can be varied to suit circumstances.

The flash gas separated in vessel 11 is re-circulated in a circuit separate from that which carries the raw natural gas except for the portion added to the liquid natural gas at 28. The major part of the cooling of the natural gas between entry into heat exchanger 5 and leaving the heat exchanger 9 is carried out by the low pressure refrigerant gas. The cooling of the natural gas in the heat exchanger 5 by the mixture of low pressure refrigerant and flash gas, is supplemented by intermediate pressure refrigerant.

The cycle described enables natural gas to be liquefied with minimum energy requirements and by having a separate refrigerant circuit start up can be effected using a separate gas such as nitrogen.

What is claimed is:

1. A process for liquefying natural gas having a content of nitrogen comprising the steps of compressing raw nitrogen-containing natural gas in gaseous form to an upper pressure level, cooling and liquefying the gas at said upper pressure level, expanding the liquid thus formed to an intermediate pressure level, further cooling the liquid and flashing it to a low pressure level to form a low pressure liquid and a flash gas, recirculating the flash gas in a circuit arranged to assist in the cooling of the natural gas at the upper pressure level by indirect heat exchange therewith, thereafter cooling the flash gas by compression and expansion to said intermediate pressure level, and adding at least part of the cooled flash gas to the liquid natural gas at said intermediate pressure level.

2. A process as claimed in claim 1 in which the flash gas is used to cool the liquid at the intermediate pressure level by indirect heat exchange before being used to cool the raw natural gas.

3. A process as claimed in claim 1 in which the part of the flash gas to be added to the liquid at intermediate pressure is first cooled by indirect heat exchange with the flash gas at low pressure.

4. A process as claimed in claim 1 wherein a part of said flash gas at said intermediate pressure level is used to assist in the cooling of said raw natural gas at said upper pressure level.

5. A process for liquefying natural gas having a content of nitrogen comprising the steps of compressing raw nitrogen-containing natural gas in gaseous form to an upper pressure level, cooling and liquefying the gas at said upper pressure level, expanding the liquid thus formed to an intermediate pressure level, further cooling said liquid and flashing it to a low pressure level to form a low pressure liquid and a flash gas, recirculating said flash gas in a recycle circuit arranged to assist in the cooling of the natural gas at the upper pressure level by indirect heat exchange therewith, thereafter cooling said flash gas by compression and expansion to said intermediate pressure level, cooling at least part of flash gas at the intermediate pressure level by indirect heat exchange with flash gas at said low pressure and adding the resulting cooled part to the liquid natural gas at said intermediate pressure level, using low pressure level flash gas to cool said liquid at said intermediate pressure level before said low pressure level flash gas is used to cool raw natural gas, using part of said flash gas at said intermediate pressure level to assist in cooling raw natural gas at said upper pressure level and expanding the remainder of the flash gas at said intermediate pressure level to said low pressure level and then mixing it with low pressure flash gas.

6. A process for liquefying natural gas having a content of nitrogen comprising the steps of compressing raw nitrogen-containing natural gas in gaseous form to an upper pressure level, cooling and liquefying the gas at said upper pressure level, expanding the liquid thus formed to an intermediate pressure level, further cooling the liquid and flashing it to a low pressure level to form a low pressure liquid and a flash gas, recirculating the low pressure flash gas in a circuit arranged to assist in the cooling of the natural gas at the upper pressure level by indirect heat exchange therewith, thereafter cooling the low pressure flash gas by compression and expansion to said intermediate pressure level, adding part of the cooled intermediate pressure level flash gas to the liquid natural gas at said intermediate pressure level, and expanding the remainder of said flash gas at intermediate pressure level to said low pressure level and mixing such expanded flash gas with said low pressure flash gas.

7. Apparatus for liquefying natural gas comprising a first compressor for compressing raw natural gas to an upper pressure level, a first heat exchanger for cooling and liquefying gas compressed to said upper pressure level, an expander for expanding liquid from said upper pressure level to an intermediate pressure level, a second heat exchanger for cooling liquid at said intermediate pressure level, expansion means for expanding liquid from said intermediate pressure level to a lower pressure level, a flash vessel for flashing liquid at said low pressure level, conduit means for conducting fluid from said first compressor in succession through said first heat exchanger, said expander, said second heat exchanger and said expansion means to said flash vessel, a re-circulation circuit for conveying flash gas from said flash vessel through said first heat exchanger to effect cooling of gas at said upper pressure level, a second compressor, an intercooler and a second expander in said re-circulation circuit for cooling flash gas coming from said first heat exchanger and bringing it to said intermediate pressure level, second conduit

means in said recirculation circuit for introducing at least a part of the gas from said second expander into the liquid at said intermediate pressure level entering said second heat exchanger, a third heat exchanger in said re-circulation circuit, third conduit means for passing flash gas from said flash vessel through said third heat exchanger to said first heat exchanger, fourth conduit means for conveying part of the gas at the intermediate pressure level from said second expander to said first heat exchanger for indirect heat exchange with natural gas from said first compressor, a third expander for expanding part of said gas at the intermediate pressure level from said second expander to said lower pressure level and fifth conduit means for introducing gas from said third expander into flash gas leaving said flash vessel.

8. Apparatus for liquefying natural gas comprising a first compressor for compressing raw natural gas to an upper pressure level, a first heat exchanger for cooling and liquefying gas compressed to said upper pressure level, an expander for expanding liquid from said upper pressure level to an intermediate pressure level, a second heat exchanger for cooling liquid at said intermediate pressure level, expansion means for expanding liquid from said intermediate pressure level to a lower pressure level, a flash vessel for flashing liquid at said low pressure level, first conduit means for conducting fluid from said first compressor in succession through said first heat exchanger, said expander, said second heat exchanger and said expansion means to said flash vessel, a re-circulation circuit for conveying flash gas from said flash vessel through said first heat exchanger to effect cooling of gas at said upper pressure level, a third conduit means in said

recirculation circuit for conveying a further part of the flash gas at intermediate pressure to said first heat exchanger to assist in the liquefaction of said raw gas, a second compressor, an intercooler and a second expander in said re-circulation circuit for cooling flash gas coming from said first heat exchanger and bringing it to said intermediate pressure level, second conduit means in said recirculation circuit for introducing at least a part of the gas from said second expander into the liquid at said intermediate pressure level entering said second heat exchanger, a third expander in said recirculation circuit for expanding the remainder of the intermediate pressure flash gas into the lower pressure level and a conduit for re-introducing the flash gas from said third expander into the flash gas leaving the flash vessel.

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WILBUR L. BASCOMB, JR., Primary Examiner

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