

(43) Date of A Publication **23.12.1998**

(22) Date of Filing 12.06.1997

(51) INT CL⁶
F25B 39/04, C09K 5/04, F25B 1/10 6/02 9/00 43/00

(71) Applicant(s)
Costain Oil, Gas & Process Limited
(Incorporated in the United Kingdom)
Costain House, Styal Road, Wythenshawe,
MANCHESTER, M22 5WN, United Kingdom

The BOC Group plc
(Incorporated in the United Kingdom)
Chertsey Road, WINDLESHAM, Surrey, GU20 6HJ,
United Kingdom

(52) UK CL (Edition P)
F4H HGXB HGXV HG2A HG2B HG2E HG2J HG2L
 HG2M HG2N HG2S HG2T

(56) Documents Cited
GB 1590891 A

(58) Field of Search
UK CL (Edition P) F4H HGXB HGXS HGXV
INT CL⁶ F25B 9/00 39/04
ONLINE DATABASE:WPI

(72) Inventor(s)
Wieslaw Henryk Isalski
John Terence Lavin
David Thomas Linnett
Philip Boustead
Adrian Joseph Finn
Terence Ronald Tomlinson

(74) Agent and/or Address for Service
Mathys & Squire
100 Grays Inn Road, LONDON, WC1X 8AL,
United Kingdom

(54) Abstract Title
A refrigeration cycle utilising a multi-component refrigerant

(57) In a refrigeration cycle utilizing a multi-component refrigerant and including at least one step of cooling and partially condensing compressed vapour and separating the condensate so formed from uncondensed vapour to form a condensate stream which is thereafter expanded and injected into returning low pressure refrigerant, a reflux heat exchanger (58) is employed in at least one of said steps of cooling and partially condensing to effect at least a part of the cooling and to separate condensate from uncondensed vapour. Condensate formed in heat exchanger (58) is recovered in line (64) condensate recovered from vapour/liquid separator (52) in line (70) may be injected, via pump (72) and line (74), into the compressed vapour stream travelling upwards through heat exchanger (58). The refrigeration cycle may be used in the liquefaction of natural gas.

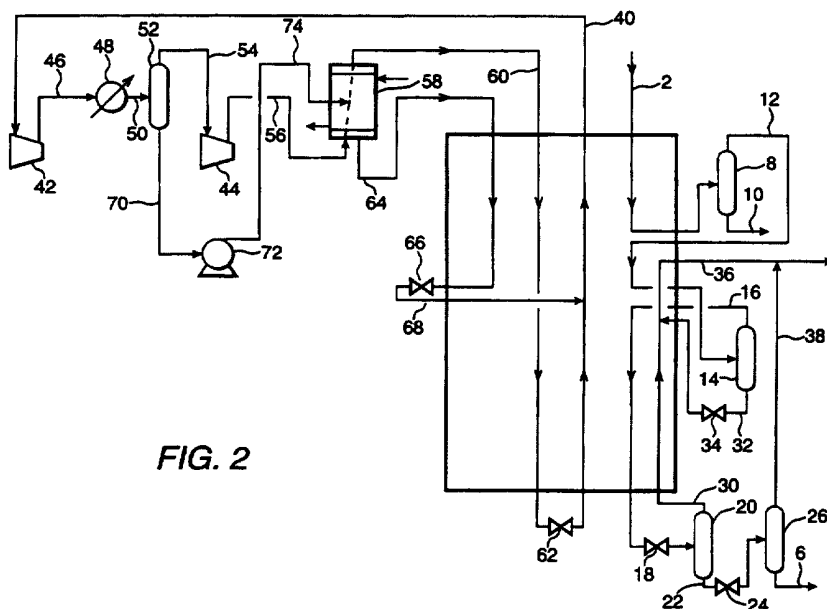


FIG. 2

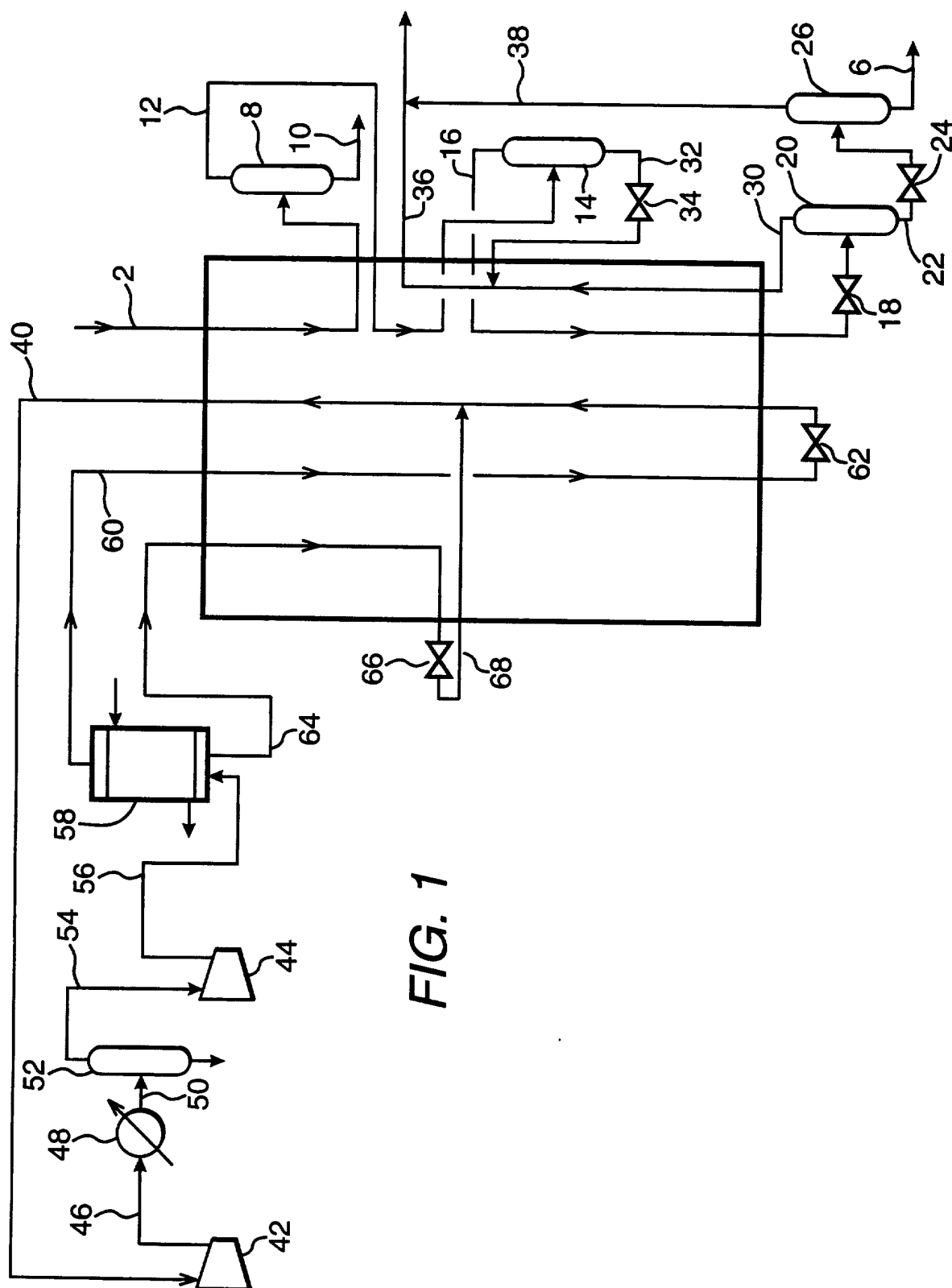


FIG. 1

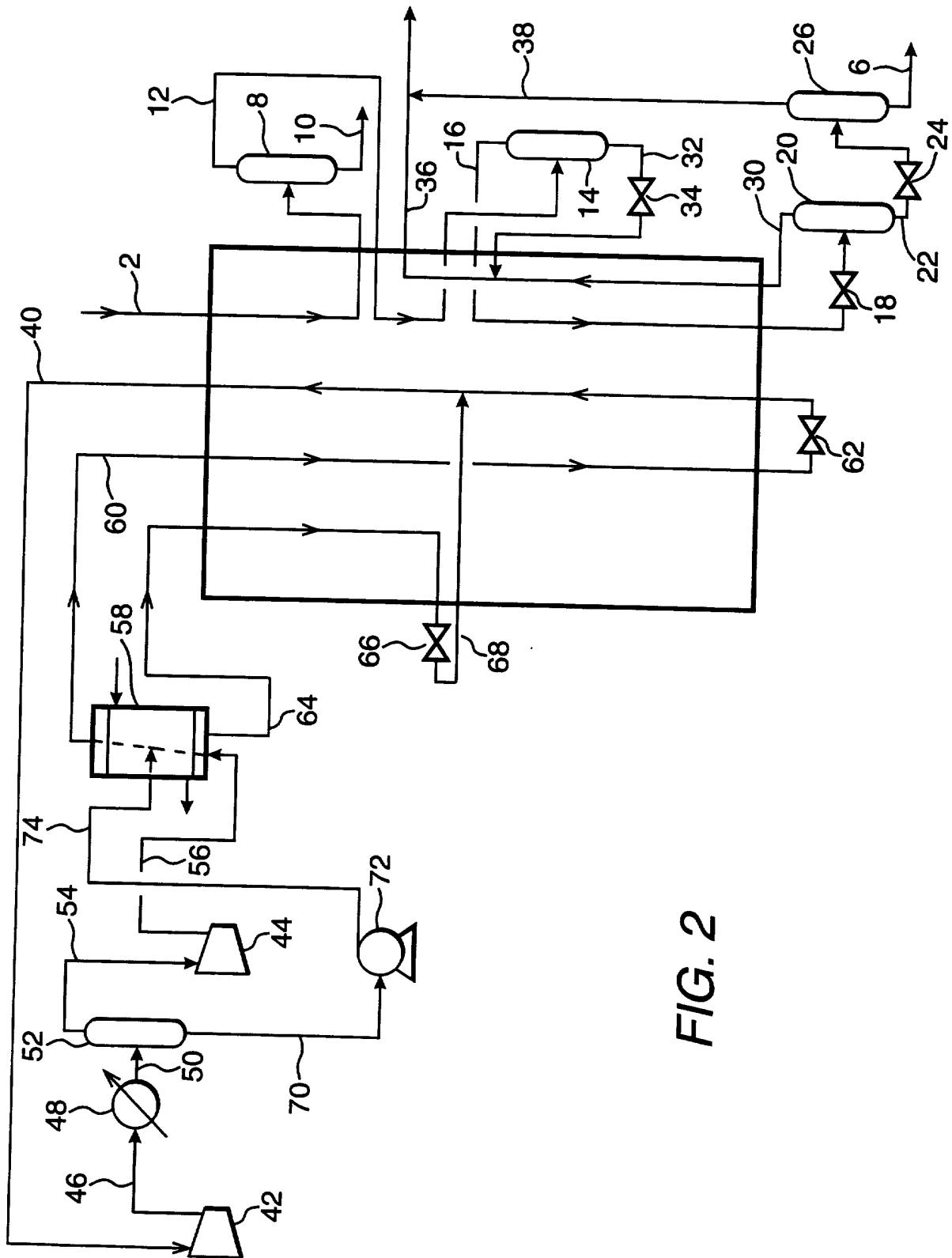


FIG. 2

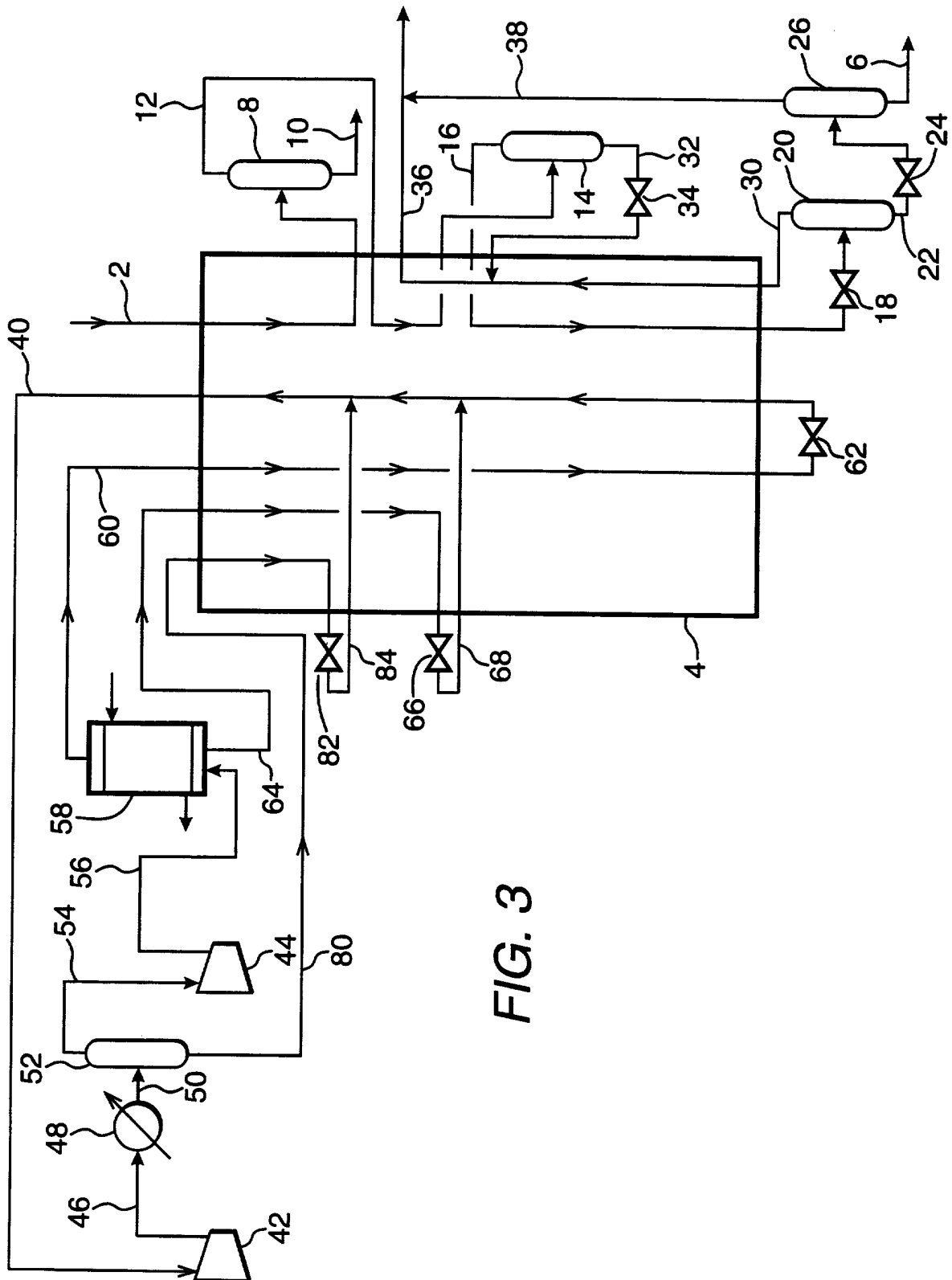


FIG. 3

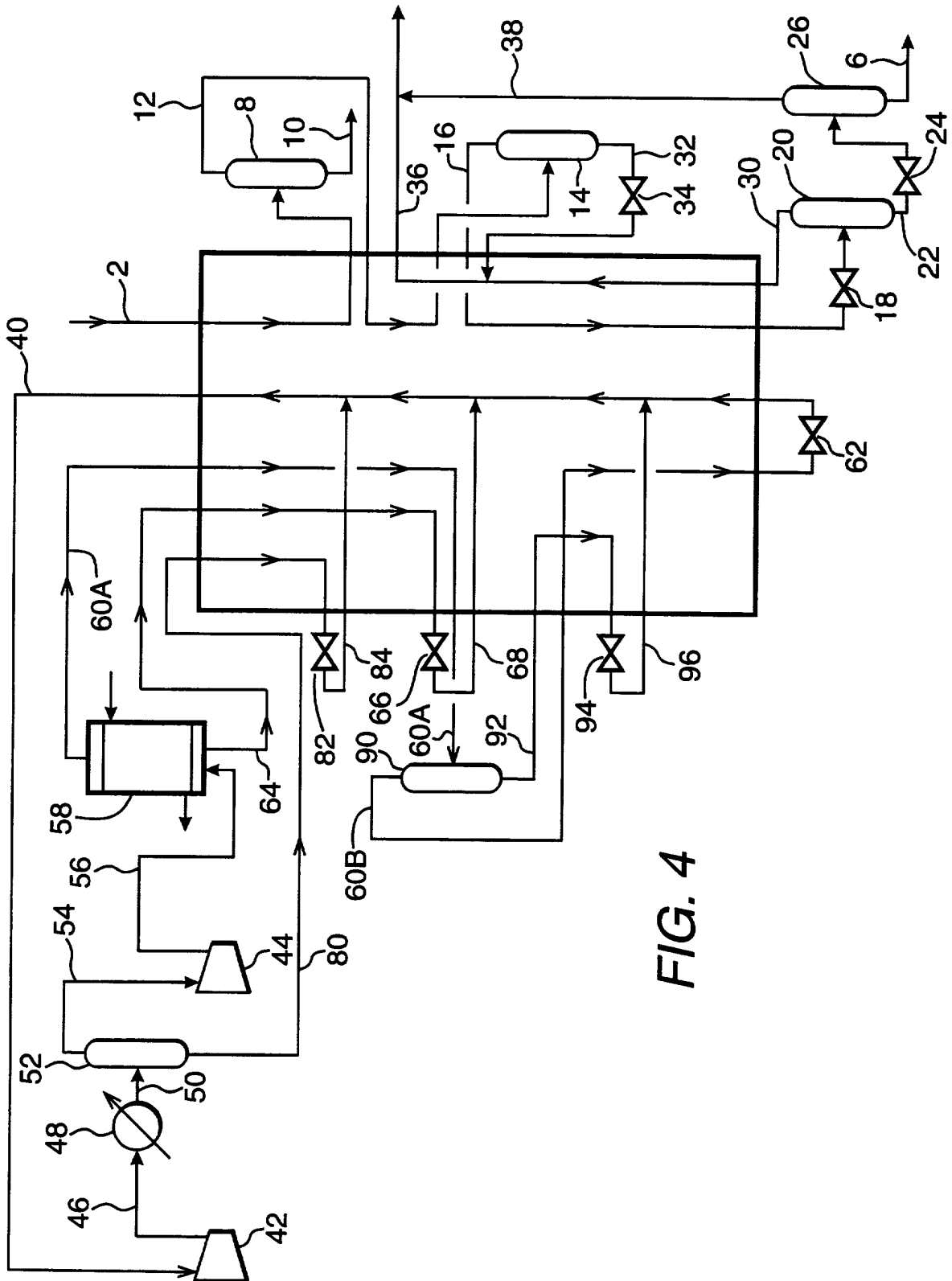


FIG. 4

REFRIGERATION CYCLE USING A MIXED REFRIGERANT

This invention relates to refrigeration cycles using a mixed refrigerant.

In a refrigeration cycle, low pressure vapour is compressed and the compressed vapour is thereafter cooled and condensed and the high pressure condensed stream expanded back to the low pressure to form a returning low pressure refrigerant stream which is vaporised to re-form the low pressure vapour stream for return to the compressor. The final cooling and condensation of the compressed vapour is effected in indirect counter-current heat exchange with the vaporising low pressure stream. Cooling of the material to be refrigerated is by heat exchange with the vaporising low pressure stream.

In a refrigeration cycle utilizing a multi-component refrigerant, sometimes known as a mixed refrigerant refrigeration cycle, the refrigerant stream is made up of a plurality of components having differing boiling points. The compressed vapour thus condenses over a range of temperatures and likewise the condensed refrigerant boils over a range of temperatures.

These mixed refrigerant refrigeration cycles are used extensively, especially but not exclusively for natural gas. Because of the wide use of these systems, improvements in efficiency are always being sought, both in the sense of economy of operation and in simplification of the plant. Because of the scale of the plants, especially for the liquefaction of natural gas, even small improvements can substantially affect the viability of a plant.

This invention provides an improvement to the mixed refrigerant refrigeration cycles currently in use.

In such refrigeration cycles, it is frequently the practice to condense a high boiling fraction from the compressed vapour, recover it from the uncondensed vapour, expand it to about the pressure of the returning low pressure refrigerant and inject it into said low pressure refrigerant. By this means, higher boiling components of the mixed refrigerant can be injected into the returning low pressure refrigerant at a temperature level where they can be most beneficial thereby improving the match between the low pressure refrigerant H/T curve and the combined cooling curve of the high pressure streams. Moreover, less of the heavy components are contained in the uncondensed vapour which is separated from the condensate and thus less total refrigerant has to be processed in the cooler parts of the heat exchanger. Also, the returning low pressure refrigerant stream below the point of injection of the expanded high boiling fraction is lighter and therefore evaporates more easily, thus improving heat transfer efficiency and reducing heat exchanger duty.

One or more such condensates having different boiling ranges may be recovered from the compressed vapour if desired and likewise expanded and injected into the returning low pressure refrigerant stream at different temperatures of the low pressure streams. For example, the condensate may be formed in the compressor after-cooler and/or in one or more stages of inter-cooling in cases where compression is effected in two or more stages. Likewise one or more such condensate streams may also be recovered from compressed refrigerant that is being cooled in indirect counter-current heat exchange with the vaporising low pressure refrigerant.

While such recovery of high pressure condensate and expansion and injection of it into the returning low pressure refrigerant stream can improve operational efficiency, a problem occurs where expansion of the condensate results in the generation of flash since this increases the complexity of the equipment required to achieve efficient distribution of the expanded condensate into the returning low pressure refrigerant stream.

It is an object of the invention to reduce or obviate this problem. According to the present invention, there is provided a refrigeration cycle utilizing a multi-component refrigerant and including at least one step of cooling and partially condensing compressed

vapour and separating the condensate so formed from uncondensed vapour to form a condensate stream which is thereafter expanded and injected into returning low pressure refrigerant and wherein, a refluxing exchanger is employed in at least one of said steps of cooling and partially condensing, to effect at least a part of the said cooling and to separate condensate from uncondensed vapour.

The invention is particularly applicable where the separated condensate stream is sub-cooled prior to expansion and injection into the returning low pressure refrigerant. By careful selection of the temperature to which the condensate is sub-cooled, it may be possible, by virtue of the invention, to expand it to the pressure of the returning low pressure without the generation of flash.

In one embodiment of the invention, which is applicable to refrigeration cycles having more than one stage of compression, a refluxing exchanger may be employed in the generation and separation of condensate between stages of compression. In another embodiment, a refluxing exchanger may be employed after the final stage of compression (or after the only stage of compression where compression is effected in a single stage). In yet another embodiment, applicable to a refrigeration cycle which includes the step or steps of cooling and partially condensing compressed refrigerant by indirect countercurrent heat exchange with vaporising returning low pressure refrigerant, a refluxing exchanger may be employed in the generation and separation of condensate. The refluxing exchanger may be used to effect all the cooling employed to form the condensate or it may be employed in series with another heat exchanger, e.g. a compressor inter-stage cooler or compressor after-stage cooler, to complete the required cooling. Any combination of the above embodiments may also be used.

The invention will now be described in greater detail with reference to preferred embodiments thereof and with the aid of the accompanying drawings in which

Figure 1 is a flow sheet of a mixed refrigerant refrigeration cycle in accordance with the invention for use in the liquefaction of natural gas;

Figure 2 is a flow sheet of a modification of the refrigeration cycle of Figure 1 wherein condensate is formed in the compressor inter-stage cooler, and

Figure 3 is a flow sheet of a modification of the refrigerant cycle of Figure 2 wherein a refluxing exchanger is employed to generate and separate a condensate stream, and

Figure 4 is a flow sheet of a modification of the refrigeration cycle of Figure 3.

In the following description, the invention will be described with reference to the liquefaction of natural gas; however, it is to be understood that the use of the refrigeration cycles of this invention is not so limited and that they are also suitable for use in other applications, eg. for other gas liquefaction processes or for purification by partial condensation techniques.

Referring now to Figure 1 of the drawings, which provides a flow sheet of a known mixed refrigerant refrigeration cycle for the liquefaction of natural gas, the natural gas which is to be liquefied, is supplied at an elevated pressure to a heat exchanger 4 through line 2 and the liquefied product is recovered through line 6. The details of the arrangement for recovering the liquefied product are not relevant to the invention and many variants are possible but in the embodiment illustrated the gas is first cooled and partially condensed to recover a heavy hydrocarbon fraction. The condensate is separated from uncondensed gas in liquid/vapour separator 8. Condensate is recovered in line 10 and the uncondensed gas is returned to a cooler section of the heat exchanger in line 12 for a further step of cooling and partial condensation with the further condensate being separated from the uncondensed gas in liquid/vapour separator 14. The uncondensed gas is again returned to the heat exchanger, this time to the cold end, in line 16 for final cooling and condensation after which it is recovered, expanded to an intermediate pressure through valve 18 and supplied to liquid/vapour separator 20 for separation of any uncondensed gas. Condensate recovered from the separator 20 in line 22 is further expanded to its final pressure in expansion valve 24 and supplied to liquid/vapour separator 26 from which the liquefied gas is recovered in line 6 as mentioned above. Uncondensed gas from separator 20 is returned via line 30 to be reheated in heat exchanger 4 and is then combined with condensed liquid in line 32 from separator 14 which has been expanded through valve 34. The combined stream is further warmed in heat exchanger 4 and then recovered therefrom in line 36. It is thereafter joined by the

cold uncondensed gas from separator 26 in line 38.

The cooling and liquefaction of the natural gas is effected in heat exchanger 4 by indirect countercurrent heat exchange with a vaporising mixed refrigerant stream in line 40. For the liquefaction of natural gas, the mixed refrigerant preferably comprises a mixture of nitrogen and C_1 to C_5 hydrocarbons.

The low pressure vaporised stream recovered from the heat exchanger in line 40 is recycled for recompression in a two stage compressor having first and second stages 42, 44. After compression in the first stage 42, the vapour is transferred via line 46 for cooling in inter-cooler 48 and then passed via line 50 to vapour/liquid separator 52 for the separation of any condensate inadvertently formed by the cooling in the inter-cooler. The vapour from separator 52 is recovered in line 54 and transferred to the second stage 44 of the compressor, the compressed vapour therefrom being collected in line 56 by which it is transferred to refluxing exchanger 58 through which it passes upwardly while being cooled and partially condensed, with the condensate falling back down the exchanger in indirect contact with the rising vapour.

Condensate formed in reflux exchanger 58 is recovered in line 64 and transferred to heat exchanger 4 wherein it is sub-cooled in indirect countercurrent heat exchange with vaporising low pressure refrigerant in line 40. The sub-cooled stream is removed from heat exchanger 4 at an intermediate point, expanded through valve 66 to about the pressure of the returning low pressure refrigerant stream and injected into it via line 68. Uncondensed vapour recovered overhead from refluxing exchanger 58 is passed through heat exchanger 4 in line 60 where the vapour is cooled and condensed in indirect countercurrent heat exchange with the vaporising refrigerant stream in line 40 and thereafter expanded through valve 62 into the low pressure line 40 to form the returning low pressure refrigerant stream.

As the condensate formed in the refluxing exchanger 58 falls back down the exchanger in direct countercurrent contact with rising vapour, this has the effect of stripping lighter components from the condensate and enhancing the condensation of heavier components

from the vapour. As a result of this it is possible, by careful choice of the temperature to which the condensate is subsequently cooled, to subsequently effect expansion of the sub-cooled condensate to about the pressure of the returning low pressure refrigerant stream with substantially no formation of flash. This in turn substantially reduces the complexity and cost of the equipment required to ensure efficient distribution of the expanded condensate into the low pressure refrigerant.

Furthermore, as the use of the refluxing exchanger reduces the content of higher boiling components in the uncondensed vapour, the overall flow of vapour in line 60 is reduced and the thermodynamic efficiency in the lower temperature section of the heat exchanger 4 is improved.

Figure 2 shows a modification of the refrigeration cycle shown in Figure 1 adapted to handle condensate formed in the compressor inter-cooler 46. In this Figure, the pipelines and apparatus components which are common to those of Figure 1 have the same reference numerals.

In the refrigeration cycle of Figure 2, inter-cooler 46 is deliberately operated so as to achieve partial condensation of the refrigerant stream recovered from compressor stage 42. The partially condensed stream is directed via line 50 to vapour/liquid separator 52 where the uncondensed vapour is recovered overhead in line 54 and processed in the manner described above with reference to the embodiment illustrated in Figure 1. Condensate is recovered from vapour/liquid separator 52 in line 70 and this condensate is pumped by pump 72 to a pressure slightly higher than that of the compressed vapour recovered from the second stage 44 of the compressor and injected via line 74 into the compressed vapour stream in line 56 travelling upwards through refluxing exchanger 58. The point in refluxing exchanger 58 at which the condensate in line 74 is injected into the rising stream of compressed vapour is determined by the temperature and composition of said condensate. Some low boilers in the condensate will be flashed off in the refluxing condenser and the balance of the condensate will travel downwardly through the refluxing exchanger to be recovered, together with the liquid condensed from compressed vapour 56, in line 64.

Figure 3 shows a variant of the arrangement illustrated in Figure 2 in which the condensate from vapour/liquid separator 52 is treated in a different way. In this Figure, pipelines and apparatus features which are common to the arrangement of Figure 2 are accorded the same reference numerals. In the arrangement shown in this drawing, condensate recovered from vapour/liquid separator 52 is transferred via line 80 to the warm end of heat exchanger 4 in which it is sub-cooled by indirect countercurrent heat exchange with vaporising returning low pressure refrigerant in line 40, recovered from the heat exchanger 4 at an intermediate point, expanded through valve 82 to about the pressure of said returning low pressure refrigerant stream and then injected into that stream through line 84.

Thus, in this embodiment, there is cooling, partial condensation and separation from the uncondensed vapour of the condensate formed after each of two stages of compression, thereby providing two condensate streams of different compositions and at different pressures, the two condensate streams being expanded and injected into returning low pressure refrigerant at different temperatures of the low pressure refrigerant. The recovery of condensate formed in the inter-stage cooler and its separate expansion and injection into the returning low pressure refrigerant stream in effect creates a complete additional refrigeration stage which leads to lower power consumption and/or a reduction in heat exchanger size.

A refrigeration cycle utilizing a multi-component refrigerant wherein the compression of low pressure refrigerant vapour is effected in at least two stages of compression with cooling, partial condensation and separation from the uncondensed vapour of the condensate formed after each of at least two of said stages thereby providing two or more condensate streams of different compositions and different temperatures, and wherein at least two of said condensate streams are expanded and injected into the returning low pressure refrigerant at different temperatures of said low pressure refrigerant is the subject of our copending application No. filed on the same day as this application under our internal reference No. 19859.

Figure 4 illustrates a modification of the embodiment illustrated in Figure 3. In this Figure, pipelines and apparatus features that are common to the arrangement of Figure 3 are accorded the same reference numerals. In Figure 3, the uncondensed compressed vapour recovered overhead from refluxing exchanger 58 in line 60 is passed completely through heat exchanger 4 where it is substantially wholly condensed prior to being expanded through valve 62 to form the low pressure returning refrigerant stream in line 40. In the embodiment illustrated in Figure 4, this uncondensed compressed vapour stream is recovered overhead from the refluxing exchanger in line 60A by which it is transferred to heat exchanger 4, entering at the warm end. In heat exchanger 4, it is cooled and partially condensed in indirect countercurrent heat exchange with vaporising returning low pressure refrigerant in line 40 and withdrawn from heat exchanger 4 at an intermediate point. The withdrawn, partially condensed, stream is transferred via line 60A to vapour/liquid separator 90 from which the uncondensed vapour is recovered overhead in line 60B and returned to heat exchanger 4 to complete its cooling and condensation in indirect countercurrent heat exchange with the vaporising returning low pressure refrigerant stream in line 40. Condensate recovered from vapour/liquid separator 90 in line 92 is returned to heat exchanger 4 for sub-cooling in indirect countercurrent heat exchange with the vaporising returning low pressure refrigerant stream in line 40 and then is withdrawn from the heat exchanger at a lower intermediate point, expanded through valve 94 to substantially the same pressure as said returning low pressure refrigerant stream and injected into that stream. This arrangement still further improves the efficiency of the refrigeration cycle and also increases its capability to handle variations in the composition, temperature and pressure of the material to be refrigerated and changes in ambient conditions.

In a further preferred embodiment, any of the condensate streams in the embodiments described above with reference to Figures 1 to 4 may be divided into two or more substreams each of which may be separately expanded and injected into returning low pressure refrigerant. Preferably one or more of these substreams is sub-cooled prior to expansion. Where two or more substreams from one condensate stream are sub-cooled, they may be sub-cooled to the same temperature or to different temperatures prior to injection into the returning low pressure refrigerant. To gain maximum benefit from this

arrangement, substreams derived from the same condensate stream should be injected into the returning low pressure refrigerant at different temperatures of said low pressure returning refrigerant.

A refrigeration cycle utilizing a multi-component refrigerant and including at least one step of partially condensing compressed vapour, forming a condensate stream by separating condensate so formed from uncondensed vapour and thereafter expanding said condensate stream and injecting said expanded condensate stream into returning low pressure refrigerant, characterised in that said expanded condensate stream is injected into said returning low pressure refrigerant in the form of at least two sub-streams formed by division of said condensate, at least two of said sub-streams being injected into the returning low pressure refrigerant at different temperatures of the returning low pressure refrigerant is the subject of our copending application No. ----- filed under our internal reference 19860.

While, in each of the embodiments described above, the refluxing exchanger is shown as replacing a compressor after cooler and associated vapour/liquid separator, it will be understood that it may also be employed additionally or alternatively to replace a compressor inter-cooler such as inter-cooler 48 and its associated vapour/liquid separator, such as separator 50. Each refluxing exchanger may also be used to provide less than all the cooling and thus used in series with a conventional inter-cooler or after cooler as well as a total replacement therefor.

One or more refluxing exchangers may also possibly be used in the generation and separation of condensate in the partial condensation of compressed vapour in indirect countercurrent heat exchange with returning low pressure refrigerant.

While the embodiment described to reference to Figure 4 has a single stage of partial condensation of the compressed vapour in indirect heat exchange with vaporising returning low pressure refrigerant and subsequent recovery of the condensate, expansion thereof and in injection of the expanded condensate into the returning low pressure refrigerant stream, it will be understood that more than one such stage may be used with

the separate recovery, expansion and injection into the returning low pressure refrigerant of each of the condensates so obtained.

While heat exchanger 4 is shown as being a single heat exchanger, its overall function may be supplied by a plurality of exchangers.

It will generally be preferred for at least any heat exchanger employed in the indirect counter-current heat exchange of compressed refrigerant with returning low pressure refrigerant to be a multi-stream plate fin type heat exchanger because such heat exchangers provide greater flexibility to efficiently process a multiplicity of different streams.

One or more of the expansion valves employed for the expansion of condensate in any part of the refrigeration cycle may, if desired, be replaced by devices in which expansion is effected with performance of external work, e.g. a turbine expander.

While the invention has been described with particular reference to the liquefaction of natural gas, it may also be used in other cryogenic applications e.g. for the liquefaction of other streams or for purification where one or more contaminants is or are removed by cooling and partial condensation. Examples include air separation, the treatment of refinery off gas, and the liquefaction of ethylene and ethane.

Any suitable combination of two or more refrigerants may be used in the mixed refrigerant cycle and the choice will depend upon the composition of the material to be refrigerated and the temperature to which it is to be cooled. Examples of suitable refrigerants include nitrogen, low boiling halogenated hydrocarbons, eg. chlorofluorocarbons, and low boiling hydrocarbons. In general however, the mixed refrigerant will usually comprise two or more of nitrogen and C_1 - C_5 hydrocarbons.

CLAIMS

1. A refrigeration cycle utilizing a multi-component refrigerant and including at least one step of cooling and partially condensing compressed vapour and separating the condensate so formed from uncondensed vapour to form a condensate stream which is thereafter expanded and injected into returning low pressure refrigerant, wherein a refluxing exchanger is employed in at least one of said steps of cooling and partially condensing to effect at least a part of the cooling and to separate condensate from uncondensed vapour.
2. A refrigerant cycle as claimed in claim 1 characterised in that the separated condensate stream is sub-cooled prior to expansion and injection into returning low pressure refrigerant.
3. A refrigerant cycle as claimed in claim 2 characterised in that the separated condensate stream is sub-cooled to a temperature at which on expansion substantially to the pressure of returning low refrigerant substantially no flash is formed.
4. A refrigeration cycle as claimed in any one of the preceding claims characterised in that it includes a plurality of stages of compression of low pressure vapour with inter-stage cooling and subsequent separation of condensates formed in said cooling and a refluxing exchanger is used in said cooling and separation of at least one said condensate.
5. A refrigeration cycle as claimed in any one of the preceding claims characterised in that it includes the step of compressor after-stage cooling and separation of the condensate so formed and wherein a refluxing exchanger is used in said cooling and separation of said condensate.
6. A refrigeration cycle as claimed in claim 5 characterised in that it includes a plurality of stages of compression of low pressure vapour with inter-stage cooling, and condensate formed in inter-stage cooling is separated from uncondensed vapour and injected into an intermediate point of the refluxing exchanger.

7. A refrigeration cycle as claimed in any one of the preceding claims characterised in that at least one step of cooling and partially condensing compressed vapour is effected by indirect countercurrent heat exchange with returning low pressure refrigerant and in at least one of said steps a refluxing exchanger is used in the generation and separation of the condensate so formed from uncondensed vapour.
8. A refrigeration cycle as claimed in any one of the preceding claims utilized for the liquefaction of natural gas.
9. A refrigeration cycle as claimed in any one of the preceding claims wherein the refrigerant comprises a mixture comprising the combination of two or more of nitrogen and C₁ to C₅ hydrocarbons.
10. A refrigeration cycle as claimed in any one of the preceding claims wherein one or more multi-stream plate fin type heat exchangers is or are employed in the cooling and partial condensation of compressed refrigerant.



Application No: GB 9712301.2
Claims searched: All

Examiner: M C Monk
Date of search: 7 October 1998

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.P): F4H (HGXB, HGXS, HGXV)

Int Cl (Ed.6): F25B (9/00, 39/04)

Other: ONLINE DATABASE:WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
X	GB 1590891 H KRIEGER Consider whole document; heat exchanger (27).	1,8 at least

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.