COMBINED CASCADE AND MULTICOMPONENT REFRIGERATION SYSTEM AND METHOD

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Related U.S. Application Data

Continuation-in-part of Ser. No. 825,526, May 19, 1969, abandoned.

References Cited

UNITED STATES PATENTS


ABSTRACT

A refrigeration system and method are disclosed for liquefying a feed stream by first subjecting the feed stream to heat exchange with a single component refrigerant in a closed, cascade cycle and, thereafter, subjecting the feed stream to heat exchange with a multicomponent refrigerant in a multiple zone heat exchanger forming a portion of a second, closed refrigerant cycle.

12 Claims, 1 Drawing Figure
COMBINED CASCADE AND MULTICOMPONENT REFRIGERATION SYSTEM AND METHOD

CROSS REFERENCE

The present application is a continuation-in-part of application Ser. No. 825,526 filed May 19, 1969 and now abandoned.

BACKGROUND OF THE INVENTION

For many years, cascade-type refrigeration cycles have been used to cool and liquify feed streams such as natural gas so that it can be stored or shipped as a liquid instead of as a gas. Such cascade cycles have commonly included a plurality of individual refrigerants having decreasing atmospheric boiling points each of which is circulated in a closed cycle in heat exchange relationship with the feed stream and with each other. Unfortunately, the use of such individual refrigerants requires a very large number of separate heat exchangers, pumps, compressors and associated piping and valving for the separate, closed loops of each stage. Even more importantly, the cooling curves of individual refrigerants do not closely match the continuous cooling curve of the feed stream, and this is of particular importance with respect to the low temperature end of the cascade system wherein very substantial amounts of horsepower are wasted by this inherent inefficiency in such cascade systems.

In an effort to solve the above-indicated disadvantages, new cycles have been proposed wherein six or more refrigerants are mixed to form a multicomponent refrigerant which is subjected to multiple partial condensations and the condensate from each partial condensation is heat exchanged against the feed stream. Since each condensate is itself a multicomponent refrigerant, its cooling curve more closely approaches that of the feed stream, and significant savings in horsepower can be achieved. At the same time however, extremely large and complex heat exchangers are required since individual tube bundles are required for each of the many condensates, vapor fractions and portions of the feed. In addition, many phase separators and spray headers are required to handle the individual fractions resulting from the multiple partial condensations. Also, the previous use of multicomponent refrigerants having six or more components has required substantial sacrifices in efficiency due to the fact that the refrigerant compressor discharge pressure had to be a compromise between the widely varying optimum pressure for the highest and lowest boiling point components of the multicomponent refrigerant.

SUMMARY OF THE INVENTION

The present invention constitutes a substantial improvement over both the classical cascade-type systems and the prior art multicomponent systems just described. This is based upon the discovery that maximum efficiency and minimum capital investment can be obtained by first cooling the feed stream in a plurality of stages using the same single component refrigerant at progressively lower pressures and temperatures, followed by, liquefying and subcooling the feed stream by heat exchange with a four component refrigerant in a simplified, two-zone exchanger. Moreover, the present invention is based upon the use of the same single component refrigerant to cool and partially condense the multicomponent refrigerant such that the fractional condensate and vapor fraction of the multicomponent refrigerant are formed independently of the heat exchange functions occurring in the main exchanger. That is, contrary to the prior art systems, the multicomponent refrigerant is not subjected to heat exchange with itself to form successive fractions. As a result, the complexity and cost of the complete refrigeration system is greatly reduced while, at the same time, achieving all of the thermodynamic benefits of having very closely matched cooling curves. In addition, the use of only four components in the multicomponent refrigerant results in a refrigerant of relatively low average molecular weight, and permits the use of a much higher, substantially more efficient compressor discharge for the multicomponent refrigerant.

BRIEF DESCRIPTION OF THE DRAWINGS

The FIGURE of the drawings is a schematic, flow diagram of the complete refrigeration system illustrating one preferred embodiment of the invention.

DETAILED DESCRIPTION

Referring to the drawing, the natural gas feed stream enters the system in line 16, after having been freed of carbon dioxide impurities, and may be at a pressure of 735 psia and a temperature of approximately 10°F. The feed stream is passed through a first heat exchanger 12 which forms the first of three, cascade heat exchangers which are supplied with a single component refrigerant such as C₂ or C₃ or C₄ hydrocarbon. For example, it is possible to use any one of ethane, propane, propylene, butane or halogenated C₂-C₄ hydrocarbon. However, it has been found that optimum temperatures may be obtained at the most ideal pressures by the use of propane as the single component hydrocarbon refrigerant, and this refrigerant will be referred to in the remainder of the description.

In the preferred practice of the invention, the natural gas feed stream is then passed through line 18 to one or other of a pair of driers 20 which remove the remaining moisture from the feed stream. The driers contain a suitable well known dessicant and are suitably piped and valved so as to be capable of alternate regeneration as is well known in the art.

The dried feed stream is then passed through line 22 to a second single component refrigerant heat exchanger 24 wherein the feed stream is cooled to approximately 30°F. The cooled feed stream is then passed through line 26 to benzene scrub column 28 from which benzene and other heavy hydrocarbons are removed as condensate through discharge line 30. A minor amount of lighter hydrocarbons including methane, ethane, and propane are also removed and may be sent to a fractionation system (not shown) so as to provide make-up refrigerants as will be subsequently described. A major portion of the flow from the bottom
of column 28 is recirculated through a steam reboiler 32 so as to provide vapor to the bottom trays of the column.

The natural gas feed stream leaves column 28 as overhead vapor and passes through line 34 to a third single component refrigerant heat exchanger 36 wherein it is cooled to approximately −29°F. The feed stream is then passed to a second phase separator 38 from which additional condensed hydrocarbons are separated and passed through line 40 back to the benzene column, via pump 42 and line 44, so as to provide reflux for the column. The natural gas feed stream leaves the top of phase separator 38 as vapor and may consist of over 90 percent methane at a pressure of approximately 705 psia and at a temperature in the order of −29°F.

The feed stream is then passed through line 46 to one tube circuit 48 of a two zone heat exchanger 50. The feed stream passes upwardly through tube circuit 48 and is cooled by a counter-flow of a first multicompontent refrigerant fraction sprayed downwardly over the tube bundle from spray header 52. This multicomponent refrigerant portion of the cycle will be hereinafter described in detail however, it may be noted that the feed stream is cooled to approximately −170°F by the time it reaches the top of tube circuit 48 in the first zone. The feed stream then passes directly into a second tube circuit 54 in the second zone and passes upwardly through this tube circuit in which it is cooled by second countercflowing multicomponent refrigerant fraction sprayed downwardly from spray header 56. The feed stream is withdrawn from the top of tube circuit 54 as a totally liquid and subcooled stream leading to a storage tank in which it may be stored at atmospheric pressure and a temperature in the order of −258°F.

Reffring back to heat exchangers 12, 24 and 36, the propane, or other single component refrigerant, is compressed in a compressor having a first stage 60 and a second stage 62. The compressed propane is cooled and totally condensed in water cooler 64 and is expanded in valve 66 before entering heat exchanger 12 at a temperature in the order of 65°F and a pressure of approximately 115 psia. Heat exchanger 12, as well as the other single component exchangers, may be of conventional design as, for example, having U-tubes submerged in the liquid propane. Thus, a portion of the liquid propane is vaporized in cooling the feed stream in the U-tubes and this vapor is returned through line 68 to an intermediate stage of compressor 62. The remaining liquid refrigerant from exchanger 12 is passed through line 70 to branch lines 72 and 90. The portion in branch line 72 is expanded by valve 74 to a pressure in the order of 61 psia and is introduced into exchanger 24 at a temperature in the order of 25°F. A second portion of the liquid refrigerant is vaporized in cooling the feed stream in exchanger 24 and is returned through line 76 to the suction side of compressor 62. The remaining liquid propane from exchanger 24 is passed through line 78 and expanded in valve 80 to a pressure in the order of 18 psia and is introduced into exchanger 86 at a temperature in the order of −35°F. This portion of the refrigerant vaporized in cooling the feed stream and the refrigerant vapor is returned through lines 82 and 84 to the suction side of compressor 60. Thus, it will be apparent that the feed stream is successively cooled in three single component refrigerant heat exchangers wherein the same refrigerant is utilized at progressively decreasing pressures and temperatures in a three-stage, cascade refrigeration cycle. Of course, the temperature of the feed stream at this point is dependent upon the pressure of the single component refrigerant and the particular refrigerant which is selected. However, it has been found that the temperature of the feed stream at this point should be below 32°F, but above −100°F. In addition, it has been found that the optimum temperature should be between 0°F and −50°F depending upon the feed stream composition.

In addition to cooling the feed stream in the above described cascade cycle, the single component refrigerant is also utilized to cool, and partly condense, the multicomponent refrigerant which is subsequently utilized to liquify and subcool the feed stream in exchanger 50. This cooling of the multicomponent refrigerant by the single component refrigerant is affected in heat exchanger 86 and 88 by the second portion of the liquid propane from exchanger 12 which is supplied through main line 70 and branch line 90. This portion of the propane refrigerant is expanded in valve 92 to a pressure in the order of 61 psia and is introduced into exchanger 86 at a temperature in the order of 25°F. A portion of the propane is vaporized in cooling the multicomponent refrigerant and is withdrawn from exchanger 86 through line 87 and is returned to the suction side of compressor 62. The remaining liquid propane is passed from exchanger 86 to exchanger 88 via line 93 and expansion valve 94 such that the propane enters exchanger 88 at a pressure in the order of 18 psia and at a temperature of approximately −35°F. This portion is vaporized in partially condensing the multicomponent refrigerant and the propane vapor is withdrawn and returned to the suction side of compressor 60 via lines 96 and 84. Thus, the propane refrigerant portion of the system comprises a closed cycle wherein the feed stream is cooled by the propane in exchangers 12, 24 and 36 while the multicomponent refrigerant is partially condensed in the propane exchangers 86 and 88. In order to compensate for any loss of refrigerant in the propane cycle, a make-up line 97 may be provided downstream of valve 66 so that liquid propane may be added as required. Alternatively, gaseous propane may be added to suction side of the compressors if liquid propane is not available.

Reference is now made to the multicomponent refrigerant portion of the system. While a great many different multicomponent mixtures could be employed in the above described system, it has been discovered that very high efficiency is obtained with a mixture consisting of only four components; namely, nitrogen, methane, ethane and propane. Furthermore, it has been discovered that the preferred composition of these four components should comprise 2–12 mole percent of nitrogen, 35–45 mole percent of methane, 32–42 mole percent of ethane, and 9–19 mole percent of propane. For example, the optimum refrigerant composition for one particular natural gas feed stream was found to comprise approximately 10 mole percent of nitrogen,
40 mole percent of methane, 35 mole percent of ethane, and 15 mole percent of propane. This refrigerant mixture was found to have an average molecular weight of 26.30 which is calculated as follows:

\[
2630 \times \frac{3,763,658}{100} = 26,30 \text{ average molecular weight}
\]

For slightly different natural gas feed streams, other optimum refrigerant compositions were found within the above-indicated ranges of component mole percents. In each case, it was unexpectedly discovered that the average molecular weight was found to be between 24 and 28 when using a single component refrigerant to precool the feed and multicomponent refrigerant prior to heat exchange therebetween.

Referring back to the drawing, the multicomponent refrigerant is compressed in compressor stages 100 and 102 having an intercooler 104 and an aftercooler 106. With regard to the pressure of the compressed multicomponent refrigerant at this point, it has been discovered that the relatively light molecular weight refrigerant mixture should be compressed to a higher pressure than that employed in prior art cycles. That is, it has been found that substantially increased efficiency results when the relatively light molecular weight refrigerant is compressed to a pressure between 500 - 1,200 psia with the optimum range being in the order of 600 - 1,000 psia. Thus, by way of example, the compressed multicomponent refrigerant vapor in line 108 may be at a pressure of 611 psia and a temperature in the order of 107°F. It is then passed through line 108 to heat exchanger 86 wherein it is cooled by the propane to approximately 30°F. Thereafter, it is passed directly through the second propane exchanger 88 from which it is discharged at a temperature in the order of –27°F and passed through line 109 to phase separator 110. At this point, the multicomponent refrigerant has been partially condensed such that the liquid condensate in the bottom of separator 110 preferably comprises about 2 mole percent of nitrogen, 24 mole percent of methane, 48 mole percent of ethane, and 26 mole percent of propane. This single-step partial condensation of the multicomponent refrigerant condenses a substantial portion of the total refrigerant flow such as, for example, 30-70 percent by volume per unit time. Accordingly, it is necessary that the multicomponent refrigerant be precooled to a temperature substantially below the freezing point of water, and preferably to a temperature in the order of 0°F to –10°F. More specifically, it has been found that the multicomponent refrigerant should be precooled in exchanger 88 to approximately the same temperature level as the feed stream in exchanger 36 which is in the range of 0°F to –50°F.

Referring back to the drawing, the liquid condensate in separator 110 is passed through line 112 to tube circuit 114 of heat exchanger 50 wherein it is subcooled to a temperature in the order of –170°F. This subcooled liquid is expanded in valve 116 to a pressure in the order of 49 psia, whereby a small portion flashes to vapor, and its temperature drops to –182°F. This liquid, and the flashed vapor, is injected into exchanger 50 via line 118 and spray header 52 so as to provide refrigerant flowing downwardly over tube circuits 48, 122 and 114. Referring back to phase separator 110, the overhead vapor preferably has a composition of 20 mole percent nitrogen, 58 mole percent methane, 19 mole percent ethane, and 3 mole percent propane. This vapor is passed through line 120 to tube circuit 122 wherein the vapor is cooled and condensed by reason of the downwardly sprayed refrigerant fraction just described. The condensed multicomponent refrigerant in tube circuit 122 passes directly into a second tube circuit 124 wherein it is subcooled to a temperature in the order of –262°F. This subcooled liquid fraction is expanded in valve 128 to a pressure in the order of 51 psia whereby a small portion is flashed to vapor and the temperature drops to approximately –269°F. This liquid and flashed vapor is injected into exchanger 50 via line 130 and spray header 56 so as to provide downwardly flowing refrigerant over the tube circuits 54 and 124. In flowing downwardly over these two tube circuits, the multicomponent liquid fraction from spray header 56 is vaporized and thereby subcools both the feed stream in circuit 54 and the multicomponent liquid fraction in circuit 124. Similarly, the multicomponent liquid fraction sprayed from spray header 52 is vaporized in heat exchange with tube circuits 48, 122, and 114. As a result, all of the multicomponent refrigerant is recombined in vapor phase at the bottom of heat exchanger 50 and it is withdrawn and passed through lines 136 and 138 to the suction side of compressor 100. Thus, the multicomponent refrigerant portion of the system forms a separate, closed cycle whereby the feed stream is most efficiently cooled from the propane level down to the final subcooled temperature of –262°F. A make-up line 140 and valve 142 may be provided to add such multicomponent refrigerant as is required to compensate for unavoidable losses. As previously mentioned, this make-up refrigerant may be obtained by fractionating the hydrocarbons discharged through line 30 from benzene column 28 and adding additional nitrogen.

From the foregoing description it will be apparent that the present invention provides a refrigerant cycle in which the feed stream is progressively cooled first by a plurality of cascade heat exchangers and secondly by an integral multicomponent heat exchanger having first and second spray zones or stages wherein the feed stream is subjected to cooling by progressive vaporization of two multicomponent liquid fractions. It will also be noted that in connection with this two-zone multicomponent exchanger, the multicomponent refrigerant is subjected to only one partial condensation, namely the partial condensation occurring in heat exchangers 86 and 88. Thus, the condensate formed in these exchangers and separated in separator 110 is merely subcooled and injected into the main heat exchanger 50, while the uncondensed portion is cooled and subcooled in the main heat exchanger before it is injected back into the shell side. It will therefore be apparent that the number of tube circuits, phase separators, and associated piping and valving is an absolute minimum while, at the same time, all of the advantages of multicomponent refrigeration are achieved in liquefying and subcooling the feed.

Lastly, it is to be understood that spray headers 52 and 56 should be designed for uniform distribution of
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7 the multicomponent liquids and flashed vapors over the tube circuits. Alternatively, a phase separator may be inserted between valve 116 and header 52, as well as between valve 128 and header 56 so as to separate the two phase fluids. In this event, the separated liquids in the bottoms of these separators may be passed to the respective spray headers, and the separated vapors are injected into exchanger 50 through lines (not shown) which enter the exchanger shell immediately adjacent headers 52 and 56. In either event, both the liquid refrigerant and the small amount of flashed vapor are injected into the column at the location of headers 52 and 56.

Having described one preferred embodiment of the present invention, what is claimed is:

1. A method of totally liquefying a gaseous, methane-rich feed stream comprising the steps of:
a. supplying said methane-rich feed stream at a superatmospheric pressure,
b. precooling said gaseous superatmospheric feed stream to a temperature within the range of 0°F to −50°F in progressive heat exchange steps with a single component hydrocarbon refrigerant undergoing vaporization at a plurality of progressively lower temperatures and pressures,
c. providing a separate and distinct multicomponent refrigerant including three hydrocarbon components having different boiling points and a fourth component having a boiling point substantially below that of methane,
d. compressing said multicomponent refrigerant to a pressure within the range of 600–1,200 psia,
e. first cooling said compressed multicomponent refrigerant to a first lower temperature by passing said multicomponent refrigerant through a compressor after-cooler in heat exchange with a nonhydrocarbon cooling fluid,
f. partially condensing a substantial portion of said multicomponent refrigerant by further precooling said multicomponent refrigerant to a temperature within the range of 0°F to −50°F in progressive heat exchange with a single component hydrocarbon refrigerant undergoing vaporization at a plurality of progressively lower pressures and temperatures,
g. phase separating all of said precooled and partially condensed multicomponent refrigerant to form a single vapor fraction and a single liquid fraction,
h. subcooling said liquid fraction in heat exchange with itself after expansion to form a first subcooled liquid fraction,
i. liquefying and subcooling all of said vapor fraction in heat exchange with said first subcooled liquid fraction, and with itself after expansion, to form a second subcooled liquid fraction,
j. totally liquefying said precooled methane-rich feed stream by further cooling said precooled methane-rich feed stream to at least its liquefaction temperature, at the superatmospheric pressure thereof, solely by progressive heat exchange steps with said first and second subcooled liquid fractions undergoing vaporization,
k. returning both of said vaporized liquid fractions for recompression according to step (d), and
l. expanding said totally liquefied methane-rich feed stream from the superatmospheric pressure at which it is totally liquefied in step (j) to a substantially reduced pressure.

2. The method as claimed in claim 1 further including the step of maintaining the composition of said multicomponent refrigerant so as to have an average molecular weight within the range of 24–28.

3. The method as claimed in claim 2 further including the step of maintaining a multicomponent refrigerant composition comprising 2–12 mole percent of nitrogen, 35–45 mole percent of methane, 32–42 mole percent of ethane, and 9–19 mole percent of propane.

4. The method as claimed in claim 1 wherein said precooled methane-rich feed stream is cooled in step (j) to a subcooled temperature which is sufficiently below its liquefaction temperature to maintain substantially all of said feed stream in liquid phase upon expansion thereof according to step (1).

5. The method as claimed in claim 1 wherein said multicomponent refrigerant consists of only four components, three of said components comprising C1 to C3 hydrocarbons and the fourth component being a nonhydrocarbon component having a normal boiling point substantially below that of methane.

6. The method as claimed in claim 2 wherein said average molecular weight is maintained in the order of 26.

7. The method as claimed in claim 1 wherein said multicomponent refrigerant is compressed to a pressure within the range of 725–1,200 psia.

8. A method of liquefying at least the major portion of a gaseous, methane-rich feed stream comprising the steps of:
a. supplying said methane-rich feed stream at a superatmospheric pressure,
b. precooling said gaseous, superatmospheric feed stream to a temperature within the range of 0°F to −50°F in progressive heat exchange steps with a single component hydrocarbon refrigerant undergoing vaporization at a plurality of progressively lower temperatures and pressures,
c. providing a separate and distinct multicomponent refrigerant including three components comprising C1–C2 hydrocarbons and one non-hydrocarbon component having a boiling point substantially below that of methane,
d. maintaining the composition of said multicomponent refrigerant by maintaining 35–45 mole percent of the C1 hydrocarbon component, maintaining 32–43 mole percent of the C2 hydrocarbon component, maintaining 9–19 mole percent of the C3 hydrocarbon component, and maintaining 2–12 mole percent of the non-hydrocarbon component,
e. further maintaining the composition of said multicomponent refrigerant so as to maintain the average molecular weight of said multicomponent refrigerant within the range of 24–28,
f. compressing said multicomponent refrigerant to a pressure within the range of 600–1,200 psia,
g. first precooling said compressed multicomponent refrigerant by passage through a compressor after-cooler in heat exchange with a first cooling fluid,
h. partially condensing 30 to 70 percent of said pre-cooled multicomponent refrigerant by further precoo ling said multicomponent refrigerant to a temperature within the range of 0°F to −50°F in heat exchange steps with a single component hydrocarbon refrigerant undergoing vaporization at a plurality of progressively lower pressures and temperatures,
i. phase separating all of said precooled and partially condensed multicomponent refrigerant to form a single vapor fraction and a single liquid fraction,
j. subcooling said liquid fraction in heat exchange with itself after expansion to form a first subcooled liquid fraction,
k. liquefying and subcooling all of said vapor fraction in heat exchange with said first subcooled liquid fraction, and with itself after expansion, to form a second subcooled liquid fraction,
l. liquefying at least the major portion of said methanol-rich feed stream by further cooling said precooled methanol-rich feed stream to a temperature substantially below minus 200°F solely by progressive heat exchange with said first and second subcooled liquid fractions undergoing vaporization,
m. returning both of said vaporized liquid fractions for recompression according to step (c), and
n. expanding said liquefied methanol-rich feed stream to a reduced pressure for storage.

9. A refrigeration system for totally liquefying a gaseous methanol-rich feed stream at superatmospheric pressure comprising the combination of:
   a. first multi-stage heat exchanger means connected to a source of a single component refrigerant and
   b. means for supplying a separate and distinct multiple component refrigerant comprising at least three hydrocarbon components having different boiling points and at least one non-hydrocarbon component having a boiling point substantially below that of methanol,
c. a compressor for compressing said multicomponent refrigerant to a superatmospheric pressure,
d. a compressor after-cooler connected to said compressor for cooling said compressed multicomponent refrigerant to a first lower temperature,
e. second multi-stage heat exchanger means connected to said after-cooler and to a source of a single component refrigerant for further cooling said precooled multicomponent refrigerant to a sufficiently lower temperature to partially condense 30 percent to 70 percent thereof in heat exchange with said single component refrigerant undergoing vaporization at a plurality of progressively lower temperatures,
f. a single phase separator connected to said second multi-stage heat exchanger means for separating said partially condensed multicomponent refrigerant into a vapor fraction and a condensed liquid fraction,
g. third heat exchanger means connected to said phase separator and including expansion means for subcooling said condensed liquid fraction in heat exchange with itself, after expansion in said expansion means, to form a first subcooled liquid fraction,
h. fourth heat exchanger means connected to said phase separator means and including expansion means for liquefying and subcooling said vapor fraction in heat exchange with said first subcooled liquid fraction, and with itself after expansion in said expansion means, to form a second subcooled liquid fraction,
and with itself after expansion in said expansion means, to form a second subcooled liquid fraction,
j. fifth heat exchanger means connected to said first heat exchanger means including first and second stages for further cooling said feed stream to at least minus 200°F solely by heat exchange with said first and second subcooled liquid fractions undergoing vaporization in said first and second stages.
k. passage means connected to the first stage of said fifth heat exchanger means for returning said first and second vaporized fractions to said compressor, and
l. expansion means connected to said fifth heat exchanger means for reducing the pressure of said further cooled feed stream to a reduced pressure.

11. A refrigeration system for liquefying at least the major portion of a methane-rich feed stream comprising the combination of:
a. first and second heat exchanger means for progressively precooling and partially condensing said feed stream in heat exchange relationship with a single component hydrocarbon refrigerant undergoing vaporization at two progressively lower temperatures,
b. a phase separator separating said partially condensed feed stream into a vapor fraction and a liquid condensate,
c. a scrub column intermediate said first and second heat exchangers, means injecting said precooled feed stream from said first heat exchanger into said scrub column, and means injecting said liquid condensate into said scrub column as reflux whereby benzene and other heavy hydrocarbons are removed from said feed stream,
d. means supplying a separate multicomponent refrigerant comprising at least three components having different boiling points including one component having a boiling point substantially below that of methane,
e. third heat exchanger means for precooling and partially condensing a substantial portion of said multicomponent refrigerant in heat exchange with a single component hydrocarbon refrigerant undergoing vaporization,
f. a phase separator connected to said third heat exchanger means for separating said partially condensed multicomponent refrigerant into a vapor fraction and a condensed liquid fraction,
g. fourth heat exchanger means connected to said separator for subcooling said condensed liquid fraction in heat exchange with itself after expansion to form a first subcooled liquid fraction,
h. fifth heat exchanger means connected to said separator for liquefying and subcooling said vapor fraction in heat exchange with said first subcooled liquid fraction, and with itself after expansion, to form a second subcooled liquid fraction, and
i. sixth heat exchanger means for liquefying at least the major portion of said precooled feed stream in heat exchange with said first and second subcooled liquid fractions undergoing vaporization.

12. The refrigeration system as claimed in claim 11 further including reboiler means operatively connected to said scrub column for heating a portion of said removed benzene and heavy hydrocarbons and re-injecting the same into the bottom portion of said column as reboil fluid.