Abstract: An expanded (102) and cooled (106) crude LNG stream (108) is separated in a nitrogen rejection column (150) into a nitrogen-enriched overhead vapor stream (130) and a nitrogen-diminished bottoms liquid stream (110). The bottoms stream (110) is pumped (112) to higher pressure, divided into first and second streams (114 & 116) and then the second stream is reduced in pressure and at least partially vaporized (118) by heat exchange (106) against the crude LNG feed stream (104) to cool said feed stream and provide (120) boilup to the nitrogen rejection column (150).
This invention relates to a process for the separation of nitrogen from a liquid natural gas stream comprising nitrogen, methane, and possibly heavier hydrocarbons.

Crude natural gas is often liquefied to enable storage of larger quantities in the form of liquid natural gas (LNG). Because natural gas may be contaminated with nitrogen, nitrogen is advantageously removed from LNG to produce a nitrogen-diminished LNG product that will meet desired product specifications. Several methods of effectuating nitrogen removal from LNG have been disclosed in the prior art.

One simple method for separating nitrogen from a LNG stream is to isentropically expand the crude LNG stream in a turbine and then inject the stream into a flash separator. The liquid product removed from the flash separator will contain less nitrogen than the crude LNG stream, whereas the vapor product will contain a higher proportion of nitrogen.

A different method is disclosed in U.S. Patent No. 5,421,165 ("the '165 patent"). A process is disclosed wherein, referring to Figure 1 thereof and reproduced as present Figure 1, crude LNG (1) is isentropically expanded in a turbine (21) and cooled in a reboiler heat exchanger (21). The cooled and expanded LNG stream is then passed through a valve (3), where it undergoes static decompression, prior to its injection into a denitrogenation column (5). Within the column, nitrogen is stripped from the falling liquid by the rising vapor, so that the vapor stream (10) exiting the top of the column is enriched with nitrogen. A liquid LNG stream (11) is withdrawn from the bottom of the column (5) as a nitrogen-diminished product. Within the column, at a level below the level of injection of the cooled, expanded LNG feed stream (4), a liquid stream (6; 8) is withdrawn and passed through the heat exchanger (2) to cool the feed and then reinjected into the column (5) at a level below that at which it had been withdrawn, to provide boilup to...
the column. In effect, the passage of the withdrawn stream through the heat exchanger provides an additional equilibrium stage of separation.

A similar method for separating nitrogen from an LNG stream replaces the turbine driven dynamic decompression with a valve for static decompression, such that the expansion takes place isenthalpically rather than isentropically. The use of the isentropic expansion in the process of the ‘165 patent allegedly permits greater methane recovery.

Another method for removing nitrogen from an LNG stream is described in U.S. Patent No. 5,041,149 (“the ‘149 patent”). This patent discloses a method of removing nitrogen from a crude natural gas stream by first cooling the stream and then passing it through a phase separator, to produce a liquid stream and a vapor stream. The liquid stream is further cooled and injected into a denitrogenation column. The vapor stream is condensed and cooled further to produce a second liquid stream, prior to injection into the denitrogenation column at a higher level than that of the first liquid stream. Nitrogen-enriched vapor is removed from the top of the column and used to cool the incoming second liquid stream. The sump of the column is divided by a baffle, one side of which is filled with liquid from the lowest tray of the column. This bottoms liquid is withdrawn and at least partially vaporized in the heat exchanger, while condensing the vapor stream from the phase separator, and returned to the column as a reflux stream to provide boilup. The liquid remaining in the reflux stream falls to the other side of the baffle in the sump. This liquid reflux is then removed as a nitrogen-diminished product stream, pumped to a higher pressure, warmed and vaporized, and then dynamically expanded to reduce the temperature and pressure of the vapor product. Similar to the reboiler heat exchange of the ‘165 patent, the reflux of the bottoms liquid serves as an additional equilibrium stage of separation.

Another similar, but thermodynamically distinct method of nitrogen separation involves isentropically expanding the crude LNG stream in a turbine, cooling the expanded stream in a reboiler heat exchanger, and then injecting the cooled, expanded stream into a thermosiphon system. The liquid from the bottom of the column is withdrawn, and a portion of it is withdrawn and pumped away as the LNG product. A second portion is recycled through the reboiler heat exchanger where it is at least partially vaporized. The partially vaporized stream is then reinjected into the column, where the vapor portion of the stream provides boilup; the liquid portion of
the stream mixes with the liquid coming off the bottom tray to provide the source of the withdrawn bottoms stream. This approach is thermodynamically different from that of the '165 and '149 patents — in this case the liquid bottoms product is the result of the mixing of the liquid from the bottom tray of the column with the liquid from the reboiled stream, rather than of a pure additional equilibrium stage of separation. This difference leads to a thermodynamic mixing loss.

A disadvantage of these prior art nitrogen separation methods is that they are each dependent upon liquid head to drive the flow of the reboiler stream. This attribute has the adverse effect of limiting the flexibility of the overall process design. For example, the available head of the column will directly affect the design of the reboiler heat exchanger, wherein the pressure drop within the heat exchanger cannot be so great as to overcome the available flow. This design limitation tends to result in the implementation of larger, more expensive heat exchangers that will have a lower pressure drop, thus allowing the column's head to drive the reboiler flow. The large capital costs of the process equipment required to effectuate nitrogen removal can have a substantial effect on the profitability of the production of LNG.

Accordingly, it is an object of the present invention to provide a process which allows for greater flexibility in the design of the equipment necessary for nitrogen rejection from an LNG stream. This greater flexibility allows for the design of relatively inexpensive process equipment, thus lowering the capital costs associated with the process.

BRIEF SUMMARY OF THE INVENTION

The present invention provides an improved process for the denitrogenation of an LNG stream contaminated by nitrogen. This process allows for economic benefits by permitting a greater flexibility in the process design.

According to the invented process, a crude LNG stream comprising between about 1% and 10% nitrogen, and the remainder methane and heavier hydrocarbons, is expanded in a means for expansion, and cooled in a heat exchanger. The resultant crude LNG stream is introduced into a nitrogen rejection column, wherein the nitrogen content of the LNG is reduced as the liquid flows down the column. A nitrogen-enriched vapor stream is withdrawn from the top of the column, and a nitrogen-diminished liquid stream is withdrawn from the bottom of the column.
The nitrogen-diminished bottoms LNG stream is pumped to a higher pressure and then divided into first and second streams, and the first stream may be collected as an LNG product if desired. The second stream is reduced in pressure and then passed through the reboiler heat exchanger, thus cooling the crude LNG stream, the pressure reduction being to a level such that the second stream is at least partially vaporized in the heat exchanger. The partially vaporized second stream is reinjected into the column at a level at or above the level of withdrawal of the nitrogen-diminished bottoms LNG stream and below the level of introduction of the crude LNG feed stream to provide column boilup. Preferably, the partially vaporized second stream is injected below the lowest separation stage, viz. lowest tray in the case of a tray column, or below the packing material in the case of a packed column.

Thus, in one aspect, the present invention provides a process for the denitrogenation of a liquid natural gas (LNG) feed stream comprising:

(a) expanding the LNG feed stream and, before or after said expansion,

(b) cooling the LNG feed stream in a heat exchanger to form a cooled, expanded LNG stream;

(c) introducing said cooled, expanded LNG stream into a nitrogen rejection column;

(d) withdrawing a nitrogen-enriched overhead vapor stream from said column;

(e) passing the bottoms stream from step (d) through a pump to increase the pressure thereof;

(f) dividing the bottoms stream into a first stream and a second stream;

(g) at least partially vaporizing said second stream by reducing in pressure and then passing through said heat exchanger;

(h) injecting said partially vaporized second stream into said column to provide boilup for the column.
In a second aspect, the invention provides an apparatus for the denitrogenation of a liquid natural gas (LNG) feed stream by a process of the invention, said apparatus comprising:

- an expander for expanding the LNG feed stream;
- a heat exchanger located before or after said expander for cooling the LNG feed stream;
- a nitrogen rejection column for separating the cooled expanded LNG feed stream into the nitrogen-enriched overhead vapor stream and the nitrogen-diminished bottoms liquid stream;
- a pump for increasing the pressure of at least said bottoms stream;
- dividing means for dividing the bottoms stream into the first stream and the second stream;
- pressure reduction means for reducing the pressure of the second stream;
- conduit means for passing the reduced pressure second stream to the heat exchanger for at least partial vaporization therein; and
- conduit means for feeding the partially vaporized second stream into the nitrogen rejection column to provide reboil to the column.

As will become apparent, several variations of this process are within the scope of the invention. For example, in one embodiment, the initial crude LNG stream is expanded in a dense fluid expander, which may be placed either upstream or downstream of the reboiler heat exchanger. In another embodiment, the reduction in pressure of the second stream may be accomplished through the use of a Joule-Thomson valve. A valve may also be placed immediately upstream of the nitrogen rejection column, such that the crude LNG stream is throttled through the valve prior to injection into the column.
BRIEF DESCRIPTION OF SEVERAL VIEWS OF THE DRAWINGS

Figure 1 is a schematic diagram reproducing Figure 1 of the '165 patent and illustrating a process for removing nitrogen from an LNG stream in accordance with that patent.

Figure 2 is a schematic diagram illustrating a process for removing nitrogen from an LNG stream in accordance with one embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention achieves flexibility of design and process economic advantages in an LNG denitrogenation operation by using, in part, a pump to drive the reboiler stream, thus permitting a higher pressure drop within the reboiler heat exchanger. This, in turn, allows a higher velocity for the reboiler stream, and, consequently, higher heat transfer coefficients in the heat exchanger can be realized, permitting the use of a smaller heat exchanger.

As will be clarified in the following description, achieving this flexibility without the need for additional equipment, and maintaining output levels and energy requirements, involves the introduction of a small thermodynamic inefficiency. However, the initial capital savings afforded by the present invention more than compensates for this thermodynamic inefficiency, especially given the ease and low expense with which it may be remedied.

The term "nitrogen-enriched stream" is used herein to mean a stream containing a higher concentration of nitrogen when compared with an initial feed stream.

The term "nitrogen-diminished stream" is used herein to mean a stream containing a lower concentration of nitrogen when compared with an initial feed stream.

The term "below" is used herein to mean at a position of lesser height, i.e., closer to the ground.

The term "above" is used herein to mean at a position of greater height, i.e., farther from the ground.

The term "boilup" is used herein to mean vapor which rises up the column.
Preferred embodiments of the invention will now be described in detail with reference to Figure 2. The following embodiments are not intended to limit the scope of the invention, and it should be recognized by those skilled in the art that there are other embodiments within the scope of the claims.

As set forth in Figure 2, high-pressure LNG stream 100, typically at a pressure of about 700 psi (4.8 MPa), containing from about 1 mol% to about 10 mol% nitrogen, and the remainder methane and possibly heavier hydrocarbons, is expanded via means 102 for expanding the LNG stream to produce lower-pressure LNG stream 104. The expansion is preferably performed isentropically, and the means for expanding the LNG stream is preferably a dense fluid expander (also known as a hydraulic turbine), but may also be a valve or other known means for expanding a fluid. Lower-pressure LNG stream 104 is cooled in reboiler heat exchanger 106 to produce cooled, expanded LNG stream 108. Reboiler heat-exchanger 106 is preferably a plate-fin heat exchanger, but may be a shell-and-tube design, or any other known means for bringing two fluid streams into a heat exchange relation with each other, without mixing the fluids. Cooled, expanded LNG stream 108 is then substantially isenthalpically expanded through valve 109 and injected into nitrogen rejection column 150, this injection preferably taking place at the top of the column. Nitrogen rejection column 150 is preferably a tray column, but may be a packed column or any other mass transfer device suitable for fractionation. A nitrogen-enriched vapor stream 130 is withdrawn from the top of column 150. This stream will typically contain more than about 30% N₂ and less than about 70% methane.

Nitrogen-diminished liquid stream 110 is withdrawn from the bottom of column 150 and pumped through pump 112 to a desired pressure. After bottoms liquid stream 110 is pumped, it is split into a first stream 114 and a second stream 116. Stream 114 may be recovered as a product LNG stream. Stream 116 is substantially isenthalpically expanded through Joule-Thomson valve 117 Joule-Thomson valve, to produce low-pressure reboiler stream 118. Valve 117 may be located at any position between the point of separation of streams 114 and 116 and the reboiler heat exchanger 106. Low-pressure reboiler stream 118 is at least partially vaporized in reboiler heat exchanger 106 to produce partially vaporized reboiler stream 120, which is then injected into the bottom of column 150, below the lowest tray in the case of a tray column, or below the packing material in the case of a packed column, to provide boilup.
In an alternative embodiment, the means for expanding the LNG stream 102 may be placed downstream of reboiler heat exchanger 106. In this manner, high-pressure stream 100 is cooled in reboiler heat exchanger 106 prior to undergoing expansion in the means for expanding the LNG stream 102.

In each of the described embodiments, valve 109 is optional, and, in the alternative, cooled LNG stream 108 can be directly injected into nitrogen rejection column 150.

A particularly preferred embodiment is herein provided wherein a crude LNG stream 100 is substantially isentropically expanded in a dense fluid expander 102 and cooled in a reboiler heat exchanger 106. This cooled, expanded LNG stream 108 is substantially isenthalpically expanded through valve 109 and injected into a nitrogen rejection column 150. Within the column, rising vapor strips the nitrogen from the falling liquid, and a nitrogen-enriched stream 130 is withdrawn from the top of the column. A nitrogen-diminished liquid stream 110 is withdrawn from the bottom of the column and its pressure is increased by passage through a pump 112. After pumping, the liquid stream is divided into a first stream 114 and a second stream 116. The second stream 116 is reduced in pressure by passage through a valve 117 to a pressure that allows low-pressure reboiler stream 118 to at least partially vaporize during its subsequent passage through the reboiler heat exchanger 106. After being at least partially vaporized in the reboiler heat exchanger, the reboiler stream 120 is reinjected into the nitrogen rejection column 150 to provide boilup.

The liquid portion of the reboiler stream mixes with the liquid from the lowest column stage upon reinjection such that the nitrogen-diminished liquid stream 110 is not exclusively the liquid from the bottom stage of the rejection column 150, or from the reboiler 106, but rather a mixture of both. There is a thermodynamic loss associated with the mixing of the liquid streams to provide the withdrawn nitrogen-diminished stream 110. However, this can easily and cheaply be compensated for by the addition of a stage or stages to the nitrogen rejection column 150.

By separating the second stream 116 from the first stream 114 after the pump 112, the flow through the reboiler heat exchanger 106 is driven by a pump 112 that would already be available to pump the LNG product, first stream 114. The reboiler heat exchanger 106 can be designed for a broad range of pressure drops based on considerations such as capital cost, and the appropriate pressure of the reboiler.
stream 118 can be attained by adjusting valve 117 upstream of the reboiler heat exchanger 106.

The flow rate of the second stream 116 can be any amount up to the total flow of the nitrogen-diminished liquid stream 110, but is preferably less than about 20% of the flow rate of the first stream 114, and may be easily optimized for the particular process. This is in contrast with the process of the '165 patent, which requires 100% of the liquid flow off of a tray to be directed through the reboiler. The smaller flow rate of the reboiler stream compared with the prior art allows the reboiler heat exchanger 106 to be reduced in size.

Also, when compared with many of the prior art processes, the present invention has the additional advantage of eliminating the nozzle required for the withdrawal of the reboiler liquid stream from the column, since bottoms liquid that would be withdrawn anyway as LNG product is employed for column reboil.

The present invention provides a significant improvement in the adaptability and flexibility of a LNG denitrogenation process through the implementation of a hydraulically different process from those of the prior art. By permitting a pump 112 to drive the reboiler heat exchanger 106, rather than relying on the column head, and including the valve 117 to control mass flow, the process may be designed to optimally perform in conjunction with a chosen reboiler heat exchanger 106 design. This flexibility can lead to a smaller capital expense at the remediable cost of a minor thermodynamic loss.

**Examples**

To more particularly demonstrate some of the important differences between the process of the present invention and the prior art, process simulations were run, using an ASPEN process simulator, comparing an embodiment of the invention ("current process") with the process disclosed in the '165 patent. The comparison basis is an equal LNG production and a satisfied fuel balance (the amount of LNG product flash required to drive a gas turbine driving the process).

**The current process**

With reference to Figure 2, following expansion in dense fluid expander 102, low pressure LNG stream 104, at a flow rate of 125,450 lbmol/h (56,900 kgmol/h), a pressure of 71.62 psi (493.8 kPa), a temperature of -243°F (-152.8°C), and
containing 2.96% N₂, 95.47% methane, 1.10% C₂ hydrocarbons, and 0.47% heavier hydrocarbons, is cooled in reboiler heat exchanger 106 to produce cooled, expanded LNG stream 108 at a temperature of -252.5°F (-158.06°C). Cooled, expanded stream 108 is throttled through valve 109 and introduced into a denitrogenation column 150 comprising 6 trays, at a pressure of 18 psi (124 kPa). An overhead vapor stream 130 is withdrawn from the top of the column 150 at a flow rate of 8,123 lbmol/h (3,685 kgmol/h), and contains 31.06% N₂, 68.94% methane, and trace amounts of heavier hydrocarbons, at a pressure of 18 psi (124 kPa) and a temperature of -261.9°F (-163.28°C). Bottoms stream 110 is withdrawn from the column 150 at a flowrate of 136,071 lbmol/h (61720 kgmol/h), a pressure of 19.45 psi (134.1 kPa), a temperature of -256.8°F (-160.44°C), and contains 1.01% N₂, 97.31% methane, 1.17% C₂ hydrocarbons, and 0.51% heavier hydrocarbons. Bottoms stream 110 is pumped to a pressure of 75 psi (517 kPa) and divided into a first stream 114 and a second stream 116. The first stream 114, at a flow rate of 117,327 lbmol/h (53,219 kgmol/h), a pressure of 75 psi (517 kPa), a temperature of -256.6°F (-160.33°C), and containing 1.01% N₂, 97.31% methane, 1.17% C₂ hydrocarbons, and 0.51% heavier hydrocarbons, is recovered as the final LNG product. The second stream 116, at a flow rate of 18,744 lbmol/h (8,502 kgmol/h) is throttled through valve 117 to a pressure of 19.74 psi (136.17 kPa) to produce low pressure reboiler stream 118, which is then introduced to reboiler heat exchanger 106 at a temperature of -256.4°F (-160.22°C), where it is partially vaporized to produce vaporized reboiler stream 120. Vaporized reboiler stream 120, which is at a temperature of -252.7°F (-158.17°C), a pressure of 19.45 psi (134.17 kPa), and has a vapor fraction of 23.7%, is injected into the bottom of column 150 to provide boilup.

This process requires approximately 229 MW of power.

Prior art process

With reference to Figure 1, following expansion in turbine 21, semidecompressed LNG stream 22, at a flow rate of 125,451 lbmol/h (56,903 kgmol/h), a pressure of 71.76 psi (494.77 kPa), a temperature of -243°F (-52.8°C), and containing 2.96% N₂, 95.47% methane, 1.10% C₂ hydrocarbons, and 0.47% heavier hydrocarbons, is cooled in indirect heat exchanger 2 to a temperature of -252.6°F (-158.1°C). This cooled, expanded stream is throttled through valve 3 and introduced into denitrogenation column 5 comprising 6 trays, at a pressure of 18 psi (124 kPa). An overhead vapor stream 10 is withdrawn from the top of the column 5.
at a flow rate of 8,122 lbmol/h (3684 kgmol/h), and contains 31.17% N₂, 68.83% methane, and trace amounts of heavier hydrocarbons, at a pressure of 18 psi (124 kPa) and a temperature of -261.9°F (-163.28°C). Bottoms stream 11 is withdrawn from the column 5 at a flowrate of 117,329 lbmol/h (53,220 kgmol/h), a pressure of 19.45 psi (134.1 kPa), a temperature of -256.8°F (-160.44°C), and contains 0.01% N2, 97.32% methane, 1.17% C₂ hydrocarbons, and 0.50% heavier hydrocarbons.

First LNG fraction 6 is withdrawn from the lowest tray of the column at a flow rate of 121,047 lbmol/h (54,906 kgmol/h), a temperature of -259.7°F (-162.06°C), a pressure of 19.74 psi (136.17 kPa), and contains 1.56% N₂, 96.81% methane, 1.14% C₂ hydrocarbons, and 0.49% heavier hydrocarbons. This first LNG fraction 6 is passed through indirect heat exchanger 2 to produce stream 7, which is at a temperature of -256.8°F (-160.44°C), a pressure of 19.45 psi (134.1 kPa), and has a vapor fraction of 3.1%. Stream 7 is returned to column 5 under the lowest tray to provide boilup. This process also requires approximately 229 MW of power.

Table 1 sets forth data of corresponding streams of these two processes in order to more clearly illustrate the comparison. The respective feed streams, 104 and 22, and the respective product streams, 114 and 11, and 130 and 10, are substantially identical with respect to all relevant properties. This equivalency of feed streams and product streams enables a valid comparison of the two processes.

As demonstrated in Table 1, a significant difference between the two processes is that the reboiler stream 118 of the current process is at a flow rate of 18,744 lbmol/h (8,502 kgmol/h), which is only 15.5% of the flow rate of the reboiler stream 6 of the ‘165 patent process, 121,047 lbmol/h (54,906 kgmol/h). This difference is attributable to the fact that, while the ‘165 patent process requires that the entire liquid flow off of a column tray be recycled through the reboiler heat exchanger, the current process optimizes the amount of flow necessary to achieve the desired separation, and therefore only recycles the amount of bottoms liquid necessary to produce the required product. Another noteworthy difference between these processes is that, while the total fluid flow through the reboiler is substantially less for the current process than for the process of the ‘165 patent, because the same amount of heat is transferred in each reboiler, a greater percentage of the reboiler stream is vaporized in the current process, 23.7% versus 3.1%. The amount of vapor actually returned to the column for boilup is therefore greater for the current process (4442 lbmol/h; 2,015 kgmol/h), than for the ‘165 patent process (3752 lbmol/h 1,702 kgmol/h).
Table 1 - comparison of the current process and the '165 patent process

<table>
<thead>
<tr>
<th>Stream and Ref. #</th>
<th>Current Process</th>
<th></th>
<th>The '165 Patent Process</th>
<th></th>
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<td></td>
<td>Flow (lbmol/h (kgmol/h))</td>
<td>(N_2) mol%</td>
<td>Temp. °F (°C)</td>
<td>Pres. Psi (kPa)</td>
</tr>
<tr>
<td>Feed 104/22</td>
<td>125,450 (56,900)</td>
<td>2.96</td>
<td>95.47</td>
<td>-243 (-152.8)</td>
</tr>
<tr>
<td>Vapor Product 130/10</td>
<td>8,123 (3,685)</td>
<td>31.06</td>
<td>68.94</td>
<td>-261.9 (-163.28)</td>
</tr>
<tr>
<td>LNG Product 114/11</td>
<td>117,327 (53,219)</td>
<td>1.01</td>
<td>97.31</td>
<td>-256.6 (-160.33)</td>
</tr>
<tr>
<td>Reboil Input Stream 118/6</td>
<td>18,744 (8,502)</td>
<td>1.01</td>
<td>97.31</td>
<td>-256.4 (-160.22)</td>
</tr>
<tr>
<td>Reboil Output Stream 120/7</td>
<td>18,744 (8,502) (vapor fraction = 23.7%)</td>
<td>1.01</td>
<td>97.31</td>
<td>-252.7 (-158.17)</td>
</tr>
</tbody>
</table>
There are several other important differences between these two processes. First, because the current process uses a portion of the withdrawn bottoms product for the reboiler stream rather than withdrawing an additional stream from the column as in the ‘165 patent process, the nozzles required by the ‘165 patent process are eliminated. This is a desirable improvement because nozzles add size to the column, require the use of additional equipment, and contribute to heat leak.

Another important difference is that the use of the pump to transfer the bottoms stream before dividing the two streams allows the reboiler heat exchanger to be driven by the pump rather than liquid head, as is the case in the ‘165 patent process. This provides an additional degree of freedom and allows for greater flexibility of design and implementation of the process. For example, valve 117 can be adjusted to compensate for a greater pressure drop in the heat exchanger. This additional flexibility may be reflected not only in the initial design of the heat exchanger, but also may be advantageously employed to compensate for unexpected process conditions.

We also note that although the overall power consumption for each of the processes is virtually identical — 229.3 MW for the current process and 229.1 MW for the prior art process — in order to provide an LNG product stream at sufficient pressure for storage, pumping the bottoms liquid stream of the current process requires nearly 16% more power than pumping the bottoms liquid stream of the prior art process (293 kW for the current process and 253 kW for the prior art process). Because the pump in the current process not only provides the product LNG stream, but also drives the reboiler, 136,071 lbmol/h (61720 kgmol/h) of bottoms liquid must be pumped in the current process, while the prior art process need only pump the 117,329 lbmol/h (53,220 kgmol/h) of product LNG. However, the increased flexibility permitted by the current process more than compensates for this minor increase in power consumption.

Although the invention has been described in detail with reference to certain embodiments, those skilled in the art will recognize that there are other embodiments within the scope of the following claims.
1. A process for the denitrogenation of a liquid natural gas (LNG) feed stream comprising:

(a) expanding the LNG feed stream and, before or after said expansion, cooling the LNG feed stream in a heat exchanger to form a cooled, expanded LNG stream;

(b) introducing said cooled, expanded LNG stream into a nitrogen rejection column;

(c) withdrawing a nitrogen-enriched overhead vapor stream from said column;

(d) withdrawing a nitrogen-diminished bottoms liquid stream from said column;

(e) passing the bottoms stream from step (d) through a pump to increase the pressure thereof;

(f) dividing the bottoms stream into a first stream and a second stream;

(g) at least partially vaporizing said second stream by reducing in pressure and then passing through said heat exchanger;

(h) injecting said partially vaporized second stream into said column to provide boilup for the column.

2. A process of Claim 1, wherein the LNG feed stream is isentropically expanded.

3. A process of any one of the preceding claims, wherein the first stream is collected as an LNG product.

4. A process of claims, further comprising isenthalpically expanding the cooled, expanded LNG stream before introducing said stream into the nitrogen rejection column.
5. A process of any one of the preceding claims, wherein the expanding of the LNG feed stream is performed before the cooling of said stream.

6. A process of any one of Claims 1 to 5, wherein the cooling of the LNG feed stream is performed before the expanding of said steam.

7. A process of any one of the preceding claims, wherein the flow rate of the second stream is less than about 20% of the flow rate of the first stream.

8. A process of any one of the preceding claims, wherein the partially vaporized second stream is injected into the nitrogen rejection column below the lowest separation stage thereof.

9. A process of any one of the preceding claims, wherein the cooled, expanded LNG stream of step (b) is introduced into the top of the nitrogen rejection column.

10. An apparatus for the denitrogenation of a liquid natural gas (LNG) feed stream by a process of Claim 1, said apparatus comprising:

   an expander for expanding the LNG feed stream;

   a heat exchanger located before or after said expander for cooling the LNG feed stream;

   a nitrogen rejection column for separating the cooled expanded LNG feed stream into the nitrogen-enriched overhead vapor stream and the nitrogen-diminished bottoms liquid stream;

   a pump for increasing the pressure of at least said bottoms stream;

   dividing means for dividing the bottoms stream into the first stream and the second stream;

   pressure reduction means for reducing the pressure of the second stream;

   conduit means for passing the reduced pressure second stream to the heat exchanger for at least partial vaporization therein; and
conduit means for feeding the partially vaporized second stream into the nitrogen rejection column to provide reboil to the column.

11. An apparatus of Claim 10, wherein the expander is a dense fluid expander.

12. An apparatus of Claim 10 or Claim 11, wherein the pressure reduction means is a Joule-Thomson valve.

13. An apparatus of any one of Claims 10 to 12, further comprising a valve for expanding the cooled, expanded LNG stream before introducing the stream into the nitrogen rejection column.

14. An apparatus of any one of Claims 10 to 13, wherein the expander is located upstream of the heat exchanger.

15. An apparatus of any one of Claims 10 to 13, wherein the expander is located downstream of the heat exchanger.

16. An apparatus of any one of Claims 10 to 15, wherein the heat exchanger is a plate-fin heat exchanger.