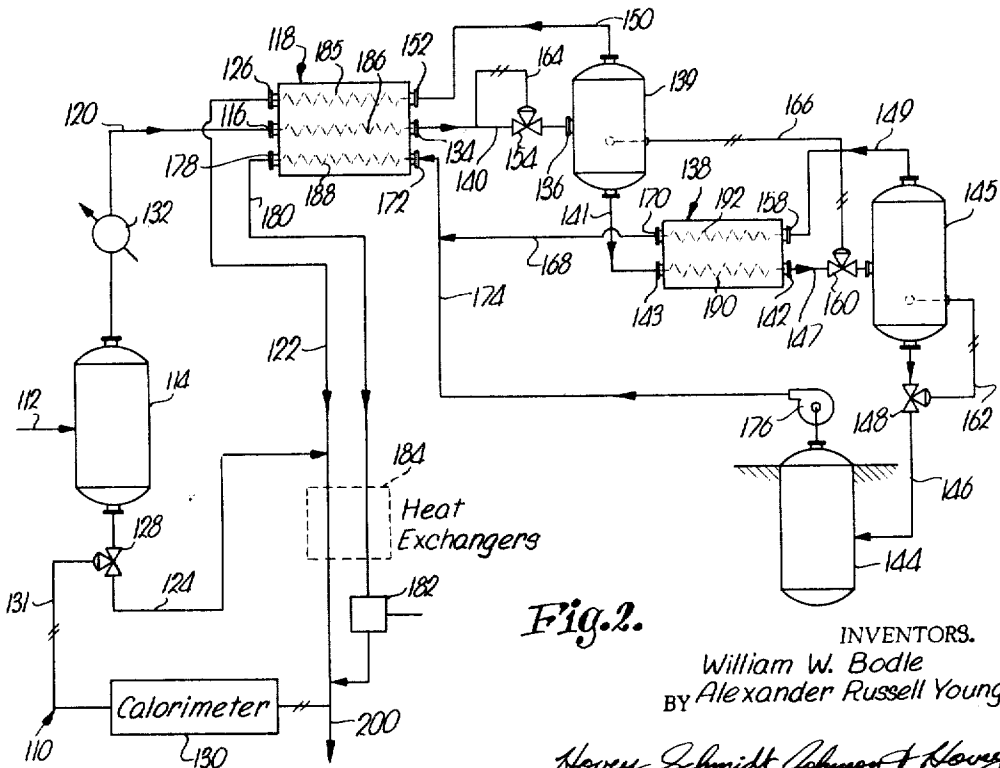
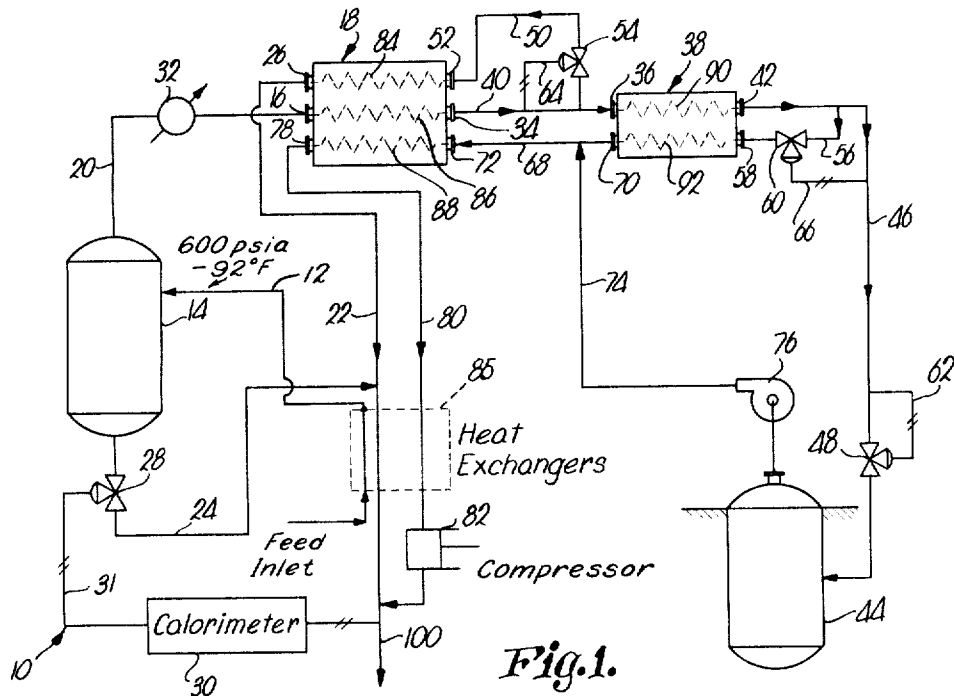


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GAS OUTPUT FROM LIQUEFIED GAS STORAGE FACILITY
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METHOD AND APPARATUS FOR CONTROLLING B.T.U. CONTENT OF GAS OUTPUT FROM LIQUEFIED GAS STORAGE FACILITY

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This invention relates to natural gas storage and transmission equipment, and particularly to an improved process and apparatus for liquefying and maintaining in storage, at least a portion of the natural gas flowing through the transmission equipment, with the B.t.u. value of the inlet gas and the outlet gas being maintained in substantial balance as gas is directed to a user from the outlet line in conjunction with supply of fresh gas to the inlet.

The use of natural gas for heating purposes in both domestic and industrial applications, has grown tremendously in recent years primarily because of the gas distribution pipe line networks that have been fabricated in all highly industrialized countries. However, the source of the natural gas is normally located a relatively great distance from the points of greatest use of the gas, thereby presenting substantial problems with respect to supply of gas to customers throughout all times of the year and under peak load conditions. During warm months of the year, substantially lesser quantities of gas are required by normal users thereof, than is the cases in extremely cold weather, and therefore, there has been a need for gas handling equipment capable of delivering required amounts of the natural gas to users regardless of climatic conditions.

The storage of natural gas in gaseous forms presents formidable obstacles, because of the large volume of gas involved and the necessity of supplying the gaseous product to users at a relatively uniform pressure, regardless of the quantity of gas needed by the customer at a particular time. Attempts to liquefy the gas for storage purposes during low demand periods were not entirely satisfactory until recent years, because of the high cost of the refrigeration equipment necessary to cool the natural gas to a level to liquefy the same, the high cost of storage containers, and also the inherent dangers associated with storage of a liquefied gaseous product above ground. These difficulties have now for the most part, been solved by the production of more efficient refrigeration apparatus, and storage of the liquefied gas product in underground caverns formed by excavation of relatively large cavities in the ground defined by frozen earth walls which confine the liquefied gas in the underground compartment.

However, it has been found that during liquefaction and storage of natural gas in a liquefied condition, problems arise due to the fact that the B.t.u. value (heat of combustion) of the inlet gas and the outlet gas from the storage facility, are not generally equal. Natural gas contains a major proportion of methane in conjunction with nitrogen and C₂ and higher hydrocarbons which will give a B.t.u. value of the order of 1,000 to 1,050 B.t.u.'s per standard cubic foot of the gas. Following liquefaction of the product, the nitrogen and methane which have been liquefied, tend to boil out of the liquefied gas storage facility first, thereby leaving the higher hydrocarbons in liquefied condition, and causing the output gas from the storage unit to have a lower B.t.u. value per standard cubic foot than the corresponding B.t.u. value of the gas flowing into the liquefaction plant and thus causing the remaining liquid in the storage unit to have a

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higher B.t.u. value. This is an undesirable condition because the sale of gas and the operation of burners using the gas are both aided by maintaining a constant B.t.u. value in the gas.

It is therefore the primary object of the present invention to provide a novel process and apparatus for liquefying and storing natural gas wherein the B.t.u. value of the output gas and the B.t.u. value of the net liquefied product are maintained in substantial balance with the B.t.u. value of the inlet gas to the liquefaction and storage facility.

It is another significant object of the invention to provide a process and apparatus for maintaining inlet and outlet natural gas streams at substantially equal B.t.u. values in a natural gas stream transmission system having a liquefied natural gas storage facility wherein a substantial proportion of the inlet gas can be liquefied without the utilization of externally operated refrigeration equipment for the entire liquefaction cycle, by virtue of the utilization of heat exchangers arranged in a novel configuration wherein expansion of a part of the product in initially liquid form, serves to lower the temperature of the remaining portion of the product to a sufficiently low level to permit storage of the liquefied gas under only atmospheric pressure in a facility such as an underground storage compartment.

A further important object of the invention is to provide an improved method and apparatus for liquefying and storing natural gas, wherein calorimeter controlled structure is employed for continuously measuring the B.t.u. value of the outlet gas from the facility and operably coupled to higher hydrocarbon fortification mechanism for adjusting the amount of higher hydrocarbons introduced into the outlet gas, to thereby maintain the B.t.u. value thereof at the same level as the B.t.u. value of the inlet gas.

Another significant object of the invention is the provision of a method and apparatus for liquefying and storing natural gas, wherein the B.t.u. value of the outlet gas is accurately controlled to maintain the same substantially equal to the B.t.u. value of the inlet gas, thereby necessarily resulting in liquefaction and storage of a product having a B.t.u. value in standard cubic feet as a gas, equal to the inlet and outlet B.t.u. gas values.

In the drawing:

FIGURE 1 is a schematic representation of preferred apparatus for liquefying and storing natural gas, employed in practicing the novel process of this invention, and adapted to maintain the B.t.u. value of the outlet gas balanced with the B.t.u. value of the inlet gas; and

FIG. 2 is a schematic representation of a modified form of apparatus for carrying out another method which also is effective in maintaining the B.t.u. values of the inlet and outlet gases substantially equal.

In the natural gas storage and liquefaction apparatus broadly designated 10 in FIG. 1, the gas inlet line 12 is coupled to a liquid separator vessel 14. Gas supplied to line 12 is first cooled in chiller 85 to a suitably low temperature. The gaseous phase outlet port at the top of vessel 14 is coupled to the inlet 16 of a first heat exchanger 18 by a line 20. The liquid outlet port of vessel 14 is connected to gas outlet line 22 by a line 24. One extremity of line 22 is joined to the outlet 26 of heat exchanger 18. A pneumatically or electrically controlled variable orifice control valve 28 is interposed in line 24 and is operated by a calorimeter 30 operably associated with the gas outlet line 100 by the control line 31.

A chiller 32 interposed in line 20, is adapted to be operably coupled to an external refrigeration system not shown, and preferably having a material such as ethylene or Freon therein as the refrigerant medium.

The outlet 34 of heat exchanger 18 is coupled to the inlet 36 of a second heat exchanger 38 by line 40, while

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the outlet 42 of exchanger 38 associated with inlet 36, is connected to an underground storage unit 44 through line 46. A pressure controlled, variable orifice expansion valve 48 is located in line 46 for reducing the pressure on the liquefied gas flowing through line 46, immediately prior to direction of the same into storage unit 44. Although unit 44 is represented schematically in FIG. 1 by a vessel, it is to be appreciated that this structure may take various forms, such as an underground cavern in rock, a metal walled receiver above or below ground, or an underground compartment defined at least in part by a frozen wall of earth and capped by a suitable cover to protect the liquefied natural gas product and to confine vapors therefrom within the storage facility.

A bleed line 50 communicating with line 40 between heat exchangers 18 and 38, is operably coupled to the inlet 52 of the heat exchanger 18, and has a temperature controlled, variable orifice expansion valve 54 interposed therein. Another bleed line 56 communicates line 46 with the inlet 58 of heat exchanger 38 and is provided with a temperature controlled, variable orifice expansion valve 60 therein. Control line 62 between valve 48 and line 46 permits the control structure for valve 48 to sense the pressure in line 46, while control line 64 between valve 54 and line 40 and control line 66 between valve 60 and line 46 permit the control units for valves 54 and 60 to sense the temperature of the streams in respective lines 40 and 46.

Line 68 interconnecting the outlet 70 of heat exchanger 38 with the inlet 72 of heat exchanger 18, has a T therein communicating line 68 with the storage unit 44 through the line 74. Blower 76 interposed in line 74 directs vapor above the level of liquid in storage unit 44 directly to line 68. The outlet 78 of heat exchanger 18 is connected to line 100 by line 80 having a compressor 82 therein. It is to be noted that both of the lines 22 and 80 preferably extend through heat exchangers represented schematically in the drawing and designated broadly by the numeral 85 which serve to raise the temperature of the gaseous product ultimately discharged through the terminus of the outlet line 100, while utilizing the refrigeration available in these cold streams for a useful purpose such as cooling feed gas to the liquefaction unit before it arrives at separator 14 through line 12.

The dotted lines in heat exchanger 18 and 38 represent the effective connection of the inlet and outlet ports rather than the actual arrangement of components therein, with line 84 representing the path of fluid between inlet 52 and outlet 26, while line 86 shows the effective connection between inlet 16 and outlet 34 and line 88 schematically represents the effective intercommunication of inlet 72 with outlet 78. Similarly, the dotted line 90 represents the communication between inlet 36 and outlet 42, with the line 92 representing the connection of inlet 58 with outlet 70.

Briefly describing the operation of apparatus 10, natural gas previously chilled at 85 by exchange with cold gases and refrigerants to such a temperature that partial condensation of the natural gas occurs, is introduced into the separator 14 via inlet line 12 where a proportion of higher hydrocarbons originally in the gas are collected as liquid in the lower portion of the separator vessel. The gaseous product is discharged out of the top of separator 14 through line 20 and is then passed through the ethylene chiller 32 to effect nearly complete liquefaction thereof. Continued passage of the liquid product through heat exchanger 18 via path 86, causes the temperature of the liquid to be further lowered as the same passes in thermal interchange relationship with a substantially colder vent stream as will be hereinafter explained, so that the liquefied gas is lowered to a substantially lower temperature at the outlet 34 of heat exchanger 18, than at the outlet of chiller 32. A portion of the liquefied product is removed from line 40 through bleed line 50 by way of valve 54 whereby the

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pressure on the liquefied gas is substantially lowered and effecting some further cooling thereof, so that the product flowing along path 84 in heat exchanger 18, is in countercurrent thermal interchange relationship with the product flowing along path 86. Because a substantial quantity of heat is transferred to the liquid flowing along path 84 in heat exchanger 18, the material is changed to a gaseous condition for direction to a source of use through line 22 and the outlet line 100.

Returning to the path of the remaining portion of the liquefied product in line 40, which is not bled therefrom through the line 50, it can be seen that the liquefied gas flows into heat exchanger 38 for passage along path 90. A portion of the product discharged from heat exchanger 38 through line 46, is diverted therefrom for passage through the bleed line 56 with the pressure on the stream being lowered by the expansion valve 60 so that vaporization of the product may occur along path 92 in heat exchanger 38, as the product is caused to flow in thermal interchange relationship with the liquefied gas flowing along path 90. The material discharged from heat exchanger 38 at outlet 70, also flows through heat exchanger 18 via line 68 and path 88, so that this quantity of the gas is also in thermal interchange relationship with the liquid product flowing through heat exchanger 18 between line 20 and line 40. The gaseous stream emanating from the outlet 78 of heat exchanger 18 is directed via line 80 into outlet line 100 with the compressor 82 serving to increase the pressure of the gas.

The liquefied natural gas flowing toward storage unit 44 through line 46, is further reduced in pressure and temperature by the expansion valve 48 to permit storage of the product at substantially atmospheric pressure. It is to be understood that the heat exchange and expansion operations explained above, are effective to lower the temperature of the liquefied product to a level where the same will be obtained in a substantially liquid condition for storage at atmospheric pressure. Therefore, the product should be discharged into storage unit 44 at a temperature of about -257° F. In order to permit storage of liquefied gas in unit 44 without continuous removal of substantial quantities of heat therefrom by refrigeration equipment, a certain proportion of the liquefied gas is permitted to boil off and which is directed in vapor form by blower 76 through line 74 directly into line 68.

The higher hydrocarbons in liquefied form, collected in separator 14, are removed therefrom through line 24 and directed into the gas flowing through outlet line 22 toward the distribution lines connected to the liquefaction and storage facility. The higher hydrocarbons could of course, in the alternative, be introduced into the stream in line 80 or directly into the stream in line 100. The amount of the liquid hydrocarbons of two or more carbon atoms delivered to the gas in outlet line 22 via line 24, is varied by the valve 28 under the direct control of calorimeter 30. The B.t.u. value of the gas flowing through outlet line 100 is accurately measured by the calorimeter 30, and the flow of liquid hydrocarbons from separator 14 into the gas in outlet line 22, varied in strict accordance with the B.t.u. content of the gas to thereby maintain the same at a fixed value. By maintaining the B.t.u. values of the outlet gas and the inlet gas substantially equal, it necessarily follows that the B.t.u. value in standard cubic feet of gas of the product stored in unit 44 in liquefied condition, is also of equal B.t.u. content. It is to be understood that suitable control mechanism is provided in operable association with vessel 14 for assuring collection of sufficient liquefied higher hydrocarbons in vessel 14 to provide the necessary amounts thereof for fortification of gas in line 22 under the demands of calorimeter 30 controlling the size of the orifice of valve 28. This is done by adjusting, as required, the temperature of the inlet stream to vessel 14 to liquefy more or less of the higher hydrocarbons as needed to maintain a quantity thereof in vessel 14.

In order to obtain a clearer understanding of the operation of apparatus 10, and the way in which the B.t.u. value of the outlet gas is maintained equal to the B.t.u. value of the inlet gas, representative figures for an exemplary operation will be set forth, but it is to be understood that these values are not restrictive and will vary depending upon the amount of gas supplied to apparatus 10, the composition of the gaseous product, and the proportion of the gas which is to be stored in a liquefied state. Typical operating conditions and values for apparatus of the type described, could include the supply of 5.6943 m.m.s.c.f.d. of gas to separator vessel 14 through line 12 with the gas being at a temperature of -92°F. , under a pressure of 600 p.s.i.a. and having a B.t.u. value of 1,035 B.t.u.'s per standard cubic foot. In this example, it is assumed that the composition of the natural gas is such that 0.0943 m.m.s.c.f.d. of product comprising mainly higher hydrocarbons in the original natural gas stream, will be liquefied at the temperature and pressure stated and removed from vessel 14 via line 24 under the control of calorimeter 30. The composition is also such that the higher hydrocarbons thus condensed will have a value of 1,700 B.t.u.'s per standard cubic foot. It is to be pointed out that the liquefied higher hydrocarbons will actually collect to a certain level in the lower portion of vessel 14, and that the quantity parameter set forth above represents the average amount of the liquefied hydrocarbons which are removed from the separator under the control of valve 28 during continuous operation of the apparatus.

The gaseous stream discharged from vessel 14 via line 20 is then passed through the ethylene chiller to effect nearly complete liquefaction of methane, nitrogen and other components which remain in the natural gas stream. The gaseous discharge from vessel 14 will have a B.t.u. value of 1,020 B.t.u.'s per standard cubic foot, and it is to be preferred that the liquefied ethylene directed through chiller 32 in heat exchange relationship to the product flowing through line 20, be at a temperature of about -148°F. , thereby lowering the natural gas in liquefied condition to a temperature level of about -143°F. The pressure at this point will remain at 600 p.s.i.a.

The liquefied product discharged from heat exchanger 18 at outlet 34 will be at a temperature of about -205°F. because of thermal interchange between the liquefied gas flowing along path 86 in heat exchanger 18, and the streams at lower temperatures flowing in countercurrent relationship along paths 84 and 88. It can therefore, be appreciated that the product introduced into heat exchanger 38 at inlet 36 is substantially colder than the product entering exchanger 18 at inlet 16. A portion of the product in line 40 is bled therefrom through line 50, with the pressure on the liquefied gas being lowered to about 80 p.s.i.a. across the expansion valve 54. However, the product remains mainly in liquid form, and is introduced into the heat exchanger 18 for flow along path 84 to cool the liquefied gas flowing along path 86. Because of the difference in temperatures between the products flowing along paths 84 and 86, the product from line 50 will be converted to gaseous form during heating thereof, while the temperature of the liquefied gas from line 20 is lowered to the -205°F. level found in line 40. Sufficient product is diverted from line 40 through bleed line 50, to provide 1.7 m.m.s.c.f.d. of gas at -140°F. at outlet 26 and having a B.t.u. value of 1,020 B.t.u.'s per standard cubic foot. Some cooling of the liquid product flowing from line 40 into heat exchanger 18 via line 50, is accomplished across the expansion valve 54, with the temperature of the product entering inlet 52 of heat exchanger 18 being of the order of -210°F. The controller for expansion valve 54 will vary the orifice thereof, to maintain the product at the specified temperature level.

As the liquefied product flows along path 90 in heat exchanger 38, the temperature thereof is again substantially lowered by virtue of the fact that a selected propor-

tion of the product is bled from line 46 through line 56 for passage in countercurrent relationship along path 92 between inlet 58 and outlet 70 of heat exchanger 38. The temperature of the liquefied gas discharged from outlet 42 of heat exchanger 38 will be about -240°F. , with the temperature of the liquefied gas bled from line 46 through line 56, being lowered to about -254°F. across expansion valve 60. The liquefied product entering heat exchanger 38 through inlet 58, for flow along path 92, undergoes heating in heat exchanger 38, so that the temperature of the product passing out of outlet 70 will be about -210°F. The controller for expansion valve 60, sensing the temperature of the product in line 46, maintains the quantity of the liquefied gas for flow along path 92 of heat exchanger 38, at the proper level to give the cooling required. The expansion valve 60 is also effective to lower the pressure on the product to about 17.7 p.s.i.a., with the pressure drop in the product occurring through the remainder of the line leading to outlet line 100 finally dropping the pressure of the gas down to about 14.7 p.s.i.a. at the inlet of compressor 82.

The pressure on the liquefied product in line 46 is finally dropped to about atmospheric pressure across the expansion valve 48 whereupon the temperature of the liquid is thereby lowered to the final level of -257°F. , permitting storage of the liquefied gas in unit 44 under atmospheric pressure and without the necessity of refrigerating the storage facility. Under the illustrative conditions specified, 2.5 m.m.s.c.f.d. of product at 1,035 B.t.u.'s per standard cubic foot (standard cubic feet refer to gaseous state) will be introduced into storage unit 44 during continuous operation of apparatus 10.

In order to maintain the liquefied gas in storage unit 44 in liquid condition, a predetermined proportion thereof is permitted to boil off at all times, with a boil-off of 0.9 m.m.s.c.f.d. of product at a B.t.u. value of 1,002 B.t.u.'s per standard cubic foot, maintaining the necessary balance so that the temperature of the liquefied product in storage unit 44 will be kept at -257°F. The vapor from the liquefied product in storage unit 44 is directed into line 68 through line 74 under the power of blower 76. The mixture of gas from line 74 and the product discharged from heat exchanger 38 at outlet 70, is directed into heat exchanger 18 for flow along path 88 in thermal interchange relationship with the liquefied product flowing along path 86. Thus, the gaseous product discharged from heat exchanger 18 at outlet 78, will have a temperature of -148°F. Since 0.5 m.m.s.c.f.d. of product having a B.t.u. value of 1,020 B.t.u.'s per standard cubic foot is removed from line 46 via line 56, this quantity of gas will be mixed with the proportion introduced into line 68 via line 74, resulting in a total of 3.1943 m.m.s.c.f.d. of gas of a B.t.u. value of 1,035 B.t.u.'s per standard cubic foot being delivered from the outlet line 100 during continuous operation of the apparatus. The heat introduced into the gas streams flowing through lines 22 and 80 from the heat exchangers 85 and compressor 82, results in the temperature of the final outlet gas stream in line 100 being raised to about $+50^{\circ}\text{F.}$ at a pressure of 50 p.s.i.a.

The higher hydrocarbons removed from the natural gas stream within separator 14, are introduced into the gas stream flowing through line 22 by line 24, with the 1,700 B.t.u.'s per standard cubic foot product in line 24 enriching the 1,020 B.t.u.'s per standard cubic foot gas in line 22 to thereby bring the combined gas in outlet line 100 to the required level of 1,035 B.t.u.'s per standard cubic foot, equal to the B.t.u. content of the inlet gas in line 12. The calorimeter 30 operably coupled to valve 28 accurately determines the B.t.u. content of the outlet gas and varies the amount of higher hydrocarbons delivered thereto in accordance with the needs of the system.

An alternative arrangement for liquefying and storing natural gas while maintaining the B.t.u. value of the outlet gas from the facility equal to the B.t.u. value of the inlet gas, is illustrated in FIG. 2 with the arrangement and

components illustrated in FIG. 1 being preferred only because a greater quantity of the gas product may be stored in liquefied condition than is the case with the FIG. 2 arrangement. The natural gas liquefying and storage apparatus broadly designated 110 in FIG. 2, also has a natural gas inlet line 112 which leads to a liquid separator vessel 114. The gas exhaust port of separator vessel 114 is coupled to the inlet 116 of heat exchanger 118 by line 120. The gas outlet line 200 of apparatus 110, is connected by line 122 to the outlet 126 of heat exchanger 118; while a liquid higher hydrocarbon line 124 extends between the liquid outlet of separator vessel 114 and line 122. A variable orifice calorimeter controlled valve 128 is interposed in line 124, so that the amount of higher hydrocarbon liquid delivered to line 122 may be selectively controlled. The calorimeter 130 is coupled to valve 128 through the control line 131 and is operable to continuously sense the B.t.u. value of the gas flowing through outlet line 200. The gas outlet line 120 from separator 114 passes through a heat exchanger 132 comprising the chiller portion of an ethylene refrigeration system which is not illustrated in detail in the drawing.

The outlet 134 of heat exchanger 118 is connected to the inlet 136 of a liquid separator vessel 139 by a line 140 having a pressure controlled expansion valve 154 interposed therein. The control line 164 for valve 154 senses the pressure of the liquid in line 140 upstream of valve 154.

The gas exhaust port at the upper extremity of separator vessel 139 is connected to the inlet 152 of heat exchanger 118 by a line 150, while the liquid outlet line 141 leading from the lower portion of vessel 139 is coupled to the inlet 143 of heat exchanger 138. The outlet 142 of heat exchanger 138 is joined to the inlet of another separator vessel 145 by line 147 having a level control expansion valve 160 therein. The control line 166 for valve 160 extends to a liquid level sensing device within separator vessel 139. The gas exhaust port of separator 145 is joined to the inlet 158 of heat exchanger 138 by a line 149, while the outlet 170 of heat exchanger 138 is joined to vapor line 174 by line 168.

The liquid outlet at the lower extremity of separator vessel 145 is connected directly to the liquefied gas storage unit 144 by a line 146 having a level control expansion valve 148 therein which is provided with a control line 162 which extends to a level sensing device within separator vessel 145. The storage unit 144 is of the same type as outlined with respect to unit 44 of FIG. 1 and is preferably, although not necessarily, recessed in the ground as previously described. Vapor line 174 extends from the upper extremity of storage unit 144 to the inlet 172 of heat exchanger 118 and is provided with a blower 176 therein downstream of the point of connection of the line 168 to line 174. Line 180 joined to the outlet 178 of heat exchanger 118, is coupled to gas outlet line 200, and has a compressor 182 interposed therein downstream of the heat exchangers 184 which are similar in construction and operation to previously described heat exchangers 85. Line 200 is connected to both of the lines 122 and 180 to direct outlet gas to a point of use.

The flow path of product between inlet 152 and outlet 126 of heat exchanger 118 is represented schematically by the dotted line 185 while the dotted lines 186 and 188 represent the flow paths between inlet 116 and outlet 134, and inlet 172 and outlet 180 respectively. Likewise, dotted line 190 represents the flow path between inlet 143 and outlet 142 of heat exchanger 138 and line 192 illustrates the fluid flow path between inlet 158 and outlet 170.

Apparatus 110 operates in a manner similar to the operation of apparatus 10, with the exception of the way in which the product is permitted to expand within separators 139 and 145 and which is not the case in the equivalent lines 50 and 56 of apparatus 10. Since the

previously cooled natural gas entering separator vessel 114 contains both gaseous and liquid components, the liquid fraction is collected in the lower portion of the vessel for ultimate discharge therefrom through line 124. Fortification liquid from vessel 114 is directed to the gas in line 122 under the control of valve 128. The gas discharged from vessel 114 through the upper port therein is liquefied by the ethylene flowing through chiller 132, whereby a liquid product is directed into the inlet 116 of heat exchanger 118. Successive expansion of the product in vessels 139 and 145, ultimately results in cooling of a proportion of the liquefied gas to a temperature where the same will remain in liquid condition at atmospheric pressure, within storage unit 144. Fortification of gas in line 122 by liquid higher hydrocarbon product from separator 114, operates to maintain the B.t.u. value of the outlet gas in line 200 substantially equal to the B.t.u. value of the gas in the inlet line 112 and necessarily results in the liquefied product in storage unit 144 also having a B.t.u. value equivalent to the inlet and outlet gas streams.

Again setting forth an illustrative example of typical conditions for continuous operation of apparatus 110 in a manner similar to the example described above with respect to apparatus 10, it may be assumed that 5.818 m.m.s.c.f.d. of natural gas containing nitrogen, methane and higher hydrocarbons, is supplied to the separator vessel 114 through line 112. This gas is under 600 p.s.i.a. at a temperature of -110° F., and has a B.t.u. value of 1,035 B.t.u.'s per standard cubic foot. Under the specified conditions 0.218 m.m.s.c.f.d. of higher hydrocarbon liquid and having a B.t.u. content of 1,500 B.t.u.'s per standard cubic foot is collected in vessel 114. The gas from the outlet of separator 114 will thereby have a B.t.u. value of 1,015 B.t.u.'s per standard cubic foot. The gas passing out of the upper end of vessel 114 flows through chiller 132 and is lowered to a temperature of -143° F. by liquefied ethylene passing through the chiller at an inlet temperature of -148° F.

The liquefied product flowing along path 186 in heat exchanger 118, is reduced in temperature from the inlet level of -143° F., to -162° F. Expansion of the liquefied gas across valve 154 and into separator 139, further lowers the temperature of the product to -210° F. with the liquefied material flowing into heat exchanger 138 through line 141. The gas collected at the top of vessel 139 is returned to heat exchanger 118 via line 150. Gas flowing out of outlet 126 of heat exchanger 118 will have a temperature of -148° F. and the pressure of liquefied product flowing through expansion valve 154 is preferably lowered to a level of about 80 p.s.i.a. The liquefied natural gas flowing along path 190 in heat exchanger 138 will be decreased in temperature from -210° F. to about -216° F., whereby further lowering of the pressure of the liquid across expansion valve 160 to about 17.7 p.s.i.a., decreases the temperature of the product to about -254° F. The liquid in the lower portion of separator vessel 145 flows through the expansion valve 148 into storage unit 144. Valve 148 lowers the pressure of the liquid to atmospheric level, and effects further lowering of the temperature of the liquefied gas to -257° F. The gas from the overhead of separator vessel 145 flows via line 149 into exchanger 138 for flow along path 192 into line 168 leading to line 174. The temperature of the product flowing along path 192 is increased to about -215° F. from the level of -254° F. in vessel 145. The product flowing through line 168 combines with vapor from the top of the liquefied natural gas in storage unit 144, which is directed to heat exchanger 118 via line 174, whereby the gas is brought into thermal interchange relationship with the liquefied gas flowing along path 186, and resulting in the gas emanating from the outlet 178 of heat exchanger 118 and flowing in line 180, having a temperature of about -148° F.

The quantity of gas discharged from the overheads of separator vessels 139 and 145 and storage unit 144 results in 2.5 m.m.s.c.f.d. of product being introduced into the unit 144 while 3.318 m.m.s.c.f.d. of gas is discharged from the outlet line 200 and representing the combination of gas from lines 122 and 180. The 0.218 m.m.s.c.f.d. of 1,500 B.t.u.'s per standard cubic foot higher hydrocarbons introduced into line 122 via line 124, results in the outlet gas from line 200 having a B.t.u. content of 1,035 B.t.u.'s per standard cubic foot which is equal to the B.t.u. content of the product in storage unit 144, and also equal to the B.t.u. value of the inlet gas at line 112. The final quantity of outlet gas in line 200 is made up of this 1,500 B.t.u. stream plus 1.7 m.m.s.c.f.d. of 1,000 B.t.u.'s per standard cubic foot gas flowing through line 122, and 1.4 m.m.s.c.f.d. of 1,005 B.t.u.'s per standard cubic foot gas flowing through line 180. The heat exchangers 184 and compressor 182 serve to increase the temperature of the final gas to +50° F. and at a pressure of 50 p.s.i.a.

Thus, it can be seen that apparatus 10 as well as apparatus 110, operate to maintain the B.t.u. values of the inlet and outlet gas streams equal, but with a somewhat greater proportion of the gas being liquefied for storage in apparatus 10 than is the case with apparatus 110.

Having thus described the invention what is claimed as new and desired to be secured by Letters Patent is:

1. In a process of maintaining inlet and outlet natural gas streams at substantially equal B.t.u. values in a natural gas stream transmission system having a liquefied natural gas storage facility and wherein the inlet gas contains nitrogen, a major proportion of methane, and higher hydrocarbons of C₂ and above, the improved steps of: cooling the inlet gas stream to a first temperature level to effect liquefaction of a certain proportion of the higher hydrocarbons therein without effecting liquefaction of the bulk of the methane in the same; removing the liquefied higher hydrocarbons from the said inlet gas stream; then cooling the remainder of the inlet gas stream to a second temperature level to effect liquefaction thereof and producing a liquefied gas product; confining said liquefied gas product in a storage area under conditions permitting a certain proportion of said liquefied gas product to vaporize; directing the vaporized natural gas out of said storage area to form at least a portion of said outlet gas stream; and adding higher hydrocarbons from said certain proportion thereof to the outlet gas stream at a rate to maintain the B.t.u. value of the outlet gas stream in predetermined relative relationship to the B.t.u. value of the inlet gas stream.

2. A process as set forth in claim 1 wherein said remainder of the inlet gas stream lowered to said second temperature level is depressurized to substantially atmospheric pressure before the liquid product is directed into said storage area.

3. A process as set forth in claim 1 wherein the amount of said liquid product permitted to vaporize is the quantity which thermally maintains the temperature of the liquid product at said second temperature level.

4. Gas transmission apparatus for natural gas having nitrogen, a major proportion of methane and C₂ and higher hydrocarbons therein, comprising: a gas inlet line; a gas outlet line; structure coupled to said inlet line for cooling the natural gas flowing therethrough to a first temperature level to effect liquefaction of a certain proportion of the higher hydrocarbons in the gas without effecting liquefaction of the bulk of the methane therein; said structure including means for separating the gaseous phase from the liquid phase of the natural gas product; components operably connected to said structure for cooling the gaseous phase of the natural gas emanating from said structure to a second temperature level to effect

liquefaction thereof and producing a liquefied gas product; a storage unit coupled to said components for receiving the liquefied gas product therefrom; pipe means coupling the storage unit to said outlet line for directing vapor from the liquefied gas product in the storage unit to the outlet line; and means operably associated with said outlet line and the separating means of said structure for adding a sufficient quantity of higher hydrocarbons collected from said structure to the outlet gas stream in said outlet line at a rate to substantially equalize the B.t.u. values of the inlet gas stream and the outlet gas stream in respective lines.

5. Apparatus as set forth in claim 4 wherein said components include conduit means between said structure and the storage unit, heat exchange means operably associated with said conduit for lowering the temperature of the gas emanating from said structure to a level to liquefy the same, a pair of expansion valves interposed in said conduit downstream of said heat exchange means, a liquid separator in the conduit downstream of each of the expansion valves, and fluid conveying means coupled to said liquid separators and the outlet line for conveying the gaseous phase product from said separators to the outlet line.

6. Apparatus as set forth in claim 5 wherein is provided second heat exchange means in said fluid conveying means and said conduit means for bringing the products flowing therethrough into thermal interchange relationship, said second heat exchange means being located between said expansion valves.

7. Apparatus as set forth in claim 4 wherein said components include conduit means between the structure and said storage unit, a pair of heat exchangers in series relationship in said conduit means, a first line communicating the conduit means at a point between said heat exchangers with the outlet line and operably coupled with the first heat exchanger downstream of said structure for bringing the liquefied gas product removed from the conduit means into heat exchange relationship with the liquefied gas product flowing through the conduit means in countercurrent relationship, an expansion valve in said first line between the conduit means and said first heat exchanger, and a second line communicating the conduit means to a point downstream of the second heat exchanger with the outlet line and operably coupled to said second heat exchanger for bringing the liquefied gas product removed from the conduit means into heat exchange relationship with the liquefied gas product flowing through the conduit means in countercurrent relationship.

8. Apparatus as set forth in claim 7 wherein said second line is coupled to said first heat exchanger for bringing said product removed from the conduit means and passed through said second conduit means into thermal interchange relationship to the liquefied gas product flowing through said conduit means in countercurrent relationship.

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