This invention relates to the liquefaction of gas and more particularly to a method for the liquefaction of natural gas which is normally composed mostly of methane but may contain relatively small proportions of both higher hydrocarbons and lower boiling-point components such as nitrogen. The general system is similar, but represents an improvement over that disclosed in U.S. Patent No. 3,020,723 to De Lury et al. The invention is particularly concerned for the liquefaction of natural gas that is lean in components which exhibit higher vapor pressures than methane (such as nitrogen, hydrogen and helium).

According to the invention, natural gas enters the plant at a high pressure and is cooled and liquefied by heat exchange for use with an ethylene, propane and methane cascade refrigeration system, as is also done in the De Lury patent mentioned above. However, instead of employing a closed system of pure methane refrigerant in the final refrigeration stages, the final cooling is achieved by flashing the liquefied natural gas, and the flash vapors are then re-compressed and recycled to the inlet feed gas stream, thereby eliminating the separate heat exchangers previously needed to cool and condense the methane refrigerant. In addition, a portion of the liquefied gas is withdrawn from the main stream prior to subcooler 18 and is passed through the cold flash gases which are subsequently compressed for recycling to the inlet gas feed stream mentioned above to avoid feeding extremely cold gas to the compressors. The use of flash drums in the low levels eliminates more costly heat exchangers.

As is apparent from the above, the main object is to reduce the power required for liquefying natural gas, to simplify the process and reduce the equipment required. The specific nature of my invention, as well as other objects and advantages thereof, will clearly appear from a description of a preferred embodiment as shown in the accompanying drawings in which the figure is a flow diagram illustrating the process of the invention for the liquefaction of natural gas.

While the flow chart of the drawing shows in detail one system for the practice of the invention, with temperatures and pressures given for a typical type of gas at a particular initial pressure and temperature, it will be understood that this is merely exemplary, and that the operating conditions and subdivision of stages may be varied in accordance with known design considerations to suit particular conditions and materials. In the example, the gas to be liquefied is assumed to be a lean natural gas relatively free of components that exhibit higher vapor pressure than methane, which is the principal ingredient, and which is assumed to enter the flow line 1 at a temperature of 70° F., and at a pressure of 600 p.s.i.a. The refrigeration cycle for reducing the compressed gas to a liquefied state is a modified cascade system having a sequence of refrigeration steps including: a refrigeration cycle, an ethylene refrigeration cycle, and a methane refrigeration cycle, as indicated in the drawing. Since the propane and ethylene cycles are generally similar to those employed in the De Lury Patent No. 3,020,723 mentioned above, they will be described only briefly. The temperatures and the significant pressures at various stages are as indicated in the drawing.

Gas entering at 1 is initially cooled to a temperature of approximately 30° F. in heat exchanger 2 and to a temperature of approximately —31° F. in heat exchanger 3, by heat exchange with evaporating propane from the propane cycle. The propane is stored in container 4 at 70° F. and at a pressure of 140 p.s.i.a. This is taken in line 6 through throttle valve 7 to supply the refrigeration heat to heat exchanger 2 and the pressure is reduced to produce the indicated temperature in the feed gas line 1, the propane being reduced in temperature to 25° F., at which temperature the propane vapor is conducted from the shell of heat exchanger 2 in line 8 into line 9, and hence to second stage compressor 11, where its pressure is raised from 60.6 p.s.i.a. to 140 p.s.i.a. and condensed at 70° F. by heat exchange with cooling water in exchanger 12 and returned to the storage container 4. Some of the propane is taken from the shell of heat exchanger 2 in line 14, further expanded through throttle valve 16 for the second heat exchange step in exchanger 3, and similarly returned to first stage compressor 17, where its pressure is raised from 16.4 p.s.i.a. to 60.6 p.s.i.a., at which pressure it joins the propane from line 9 for second stage compression at 13 as previously indicated. Some of the propane from line 6 is also passed through throttle valve 18 to reduce its pressure as used for cooling ethylene from the last compression stage of the ethylene cycle, from a temperature of 70° F., and then joins the stream from line 9 for second stage compression at 13 as previously described. Propane from line 14 is similarly reduced in pressure by throttle valve 19 and evaporated in heat exchanger 22 prior to rejoining the stream from heat exchanger 3, for a second stage of cooling which reduces the temperature of the ethylene in line 23 to a temperature of —25° F., at which temperature it is condensed and stored in ethylene container 24. The natural gas in line 1 now continues through several similar stages of ethylene heat exchange in exchanges 25, 26, 27 and 28, with further temperature reductions at each stage as indicated by the drawing. The ethylene in turn is similarly compressed in a series of compressors (which may be a multi-stage compressor) as indicated in the flow chart, the number of stages and the type of each stage being selected in accordance with known principles. It will be understood that the various throttle valves, e.g., valves 18, 17, 21, 16, etc., are part of conventional control devices used to maintain the proper liquid level in their respective heat exchangers.

After passing through heat exchanger 28, the feed gas is at a temperature of —144° F., and being still at a high pressure, it is now below its critical temperature and in liquid phase. The main steam of liquid natural gas continues through three more heat exchange stages in heat exchangers 31, 32 and 33 respectively, to reduce its temperature to approximately —195° F., at which point it is passed through throttle valve 35 into flash drum 36. However, a portion of the stream is diverted between heat exchangers 28 and 31 in line 37 for heat exchange with the cold flash vapors from flash drums 36 and 38, to recover the refrigeration in these vapors, and to temper the gases going into the compressors, as will now be described.

After passing through throttle valve 35, the liquefied feed gas is flashed in flash drum 36 on reducing the pressure to 70 p.s.i.a. thus lowering its temperature to —216° F. It is then passed through refrigeration throttle valve 39 into second flash drum 38, where its pressure is reduced to 27 p.s.i.a., thus lowering the temperature to —242° F.

Liquefed feed gas from line 37 is heat exchanged in exchanger 41 with the flash vapors from flash drum 36 to raise the temperature of the flash vapor in line 42 to —150° F., and correspondingly cool the liquid methane, which is then passed through throttle valve 43 to control the rate of flow returned to the main stream in line 1.
and thence into flash drum 36, together with the main stream of liquefied feed gas in line 1. Similarly, liquefied feed gas in line 37 is withdrawn in line 44 for heat exchange in exchanger 46 with flash vapors from flash drum 38, and then passed through throttle valve 47 into flash drum 38. The remaining liquefied feed gas in line 37 is used in heat exchanger 48 to temper the vapors in line 49, which are now substantially at atmospheric pressure.

Liquefied gas at —242° F. from flash drum 38 continues on main line 1 through final stage heat exchanger 51, where its temperature is reduced to —251° F. by heat exchange with evaporating liquid withdrawn from line 1 through throttle valve 52. A full pressure reduction stage and throttle valve 53 reduces the pressure of the liquefied gas to slightly above atmospheric pressure, and a temperature of —258° F., for storage in a suitable storage facility 54, which may be an in-ground large-scale storage tank, or any other suitable storage facility, in which it is stored essentially as a boiling liquid at slightly above atmospheric pressure. Since it is in a boiling condition, vapors are removed on line 56 from the storage tank 54 and compressed by a low pressure blower 57 into line 58, where it joins the vapor stream in line 49 for the first stage of compression by methane compressors 59, 60, 61, which may be a multistage single compressor, or a raising the pressure of the methane in lines 49, 45 and 42 respectively in the indicated in the flow chart. After leaving compressor 61, the methane, now at 275 psig and above ambient temperature is cooled by cooling water heat exchange in exchanger 63 to 70° F., where some of it may be used on line 64 as plant fuel. The remainder of the methane is passed in line 66 through additional compressor stage 67 to line 68, and after further water cooling in exchanger 69, is returned on line 71 at a temperature of 70° F. and at the pressure of the incoming natural gas, to the feed gas stream on line 1. It will be noted that any small amount of impurities of higher vapor pressure than methane (e.g., nitrogen) will ultimately be removed on line 64 with the feed gas stream, and therefore do not require special treatment. For high concentrations of high vapor pressure impurities, the impurities may be removed by conventional means.

It will be apparent that the embodiments shown are only exemplary and that various modifications can be made in construction and arrangement within the scope of my invention as defined in the appended claims.

I claim:
1. The method of liquefying a gas comprising
   (a) supplying the gas in a main feed stream at high pressure and essentially ambient temperature,
   (b) removing heat from the gas to cool the gas to a temperature at which it is in a liquid state at said high pressure,
   (c) withdrawing from said main feed stream a portion of the liquefied gas from step (b) as a side stream,
   (d) subcooling the rest of the gas in said main stream to a still lower temperature than the gas in the side stream,
   (e) throttling said subcooled liquid gas from step (d) into a flash drum at a reduced pressure to flash off part of the gas as a vapor and still further cool the residual liquid gas,
   (f) heat exchanging liquefied gas from said side stream of step (e) with the flash vapor from step (e) to further subcool said liquefied side stream gas,
   (g) throttling said liquefied subcooled side stream gas of step (f) into the flash drum to rejoin the main stream,
   (h) throttling the subcooled main stream liquefied gas into a storage container as liquefied gas at substantially atmospheric pressure,
   (i) withdrawing vapor from said storage container to maintain the pressure in said container at substantially atmospheric pressure,
   (j) compressing said vapor in multi-stage compression and cooling said compressed vapor to ambient temperature,
   (k) withdrawing part of said compressed vapor for use as product, and
   (l) further compressing the remainder of said compressed vapor to about the initial pressure of the main feed stream, and returning it to the entry point of the main feed stream.

2. The method as claimed in claim 1 including
   (i) returning the flash vapor from the flash drum to the stream of vapor from said storage container at a point where the pressure of the two vapor streams is substantially equal.

3. The method of liquefying a gas comprising
   (a) supplying the gas in a main feed stream at high pressure and essentially ambient temperature,
   (b) removing heat from the gas to cool the gas to a temperature at which it is in a liquid state at said high pressure,
   (c) withdrawing from said main feed stream a portion of the liquefied gas from step (b) as a side stream,
   (d) subcooling the rest of the gas in said main stream to a still lower temperature than the gas in the side stream,
   (e) throttling said subcooled liquid gas from step (d) into a flash drum at a reduced pressure to flash off part of the gas as a vapor and still further cool the residual liquid gas,
   (f) heat exchanging liquefied gas from said side stream of step (c) with the flash vapor from step (e) to further subcool said liquefied side stream gas,
   (g) throttling said liquefied subcooled side stream gas of step (f) into the flash drum to rejoin the main stream,
   (h) throttling the subcooled main stream liquefied gas into a storage container as liquefied gas at substantially atmospheric pressure,
   (i) returning the further cooled side stream from the preceding step to further cool said side stream, and
   (j) returning the further cooled side stream from the preceding step to the main stream.

4. The method of liquefying a gas comprising
   (a) supplying the gas in a main feed stream at high pressure and essentially ambient temperature,
   (b) removing heat from the gas to cool the gas to a temperature at which it is in a liquid state at said high pressure,
   (c) withdrawing from said main feed stream a portion of the liquefied gas from step (b) as a side stream,
   (d) subcooling the rest of the gas in said main stream to a still lower temperature than the gas in the side stream,
   (e) throttling said subcooled liquid gas from step (d) into a flash drum at a reduced pressure to flash off part of the gas as a vapor and still further cool the residual liquid gas,
   (f) heat exchanging liquefied gas from said side stream of step (c) with the flash vapor from step (e) to further subcool said liquefied side stream gas,
   (g) throttling said liquefied subcooled side stream gas of step (f) into the flash drum to rejoin the main stream,
(i) further throttling the residual liquid gas from step (e) into a second flash drum at a further reduced pressure to produce vapor at a lower pressure than in step (e) and to further subcool the residual liquid gas,

(j) heat exchanging liquefied gas from the side stream of step (e) with the flash vapor from the preceding step, and

(k) throttling said liquefied subcooled side stream from the preceding step into the second flash drum to rejoin the main stream.