March 18, 1969 J. S. SWEARINGEN 3,433,026

STAGED ISENTHALPIC-ISENTROPIC EXPANSION OF GAS FROM A PRESSURIZED LIQUEFIED STATE TO A TERMINAL STORAGE STATE

Filed Nov. 7, 1966 Sheet 1 of 3

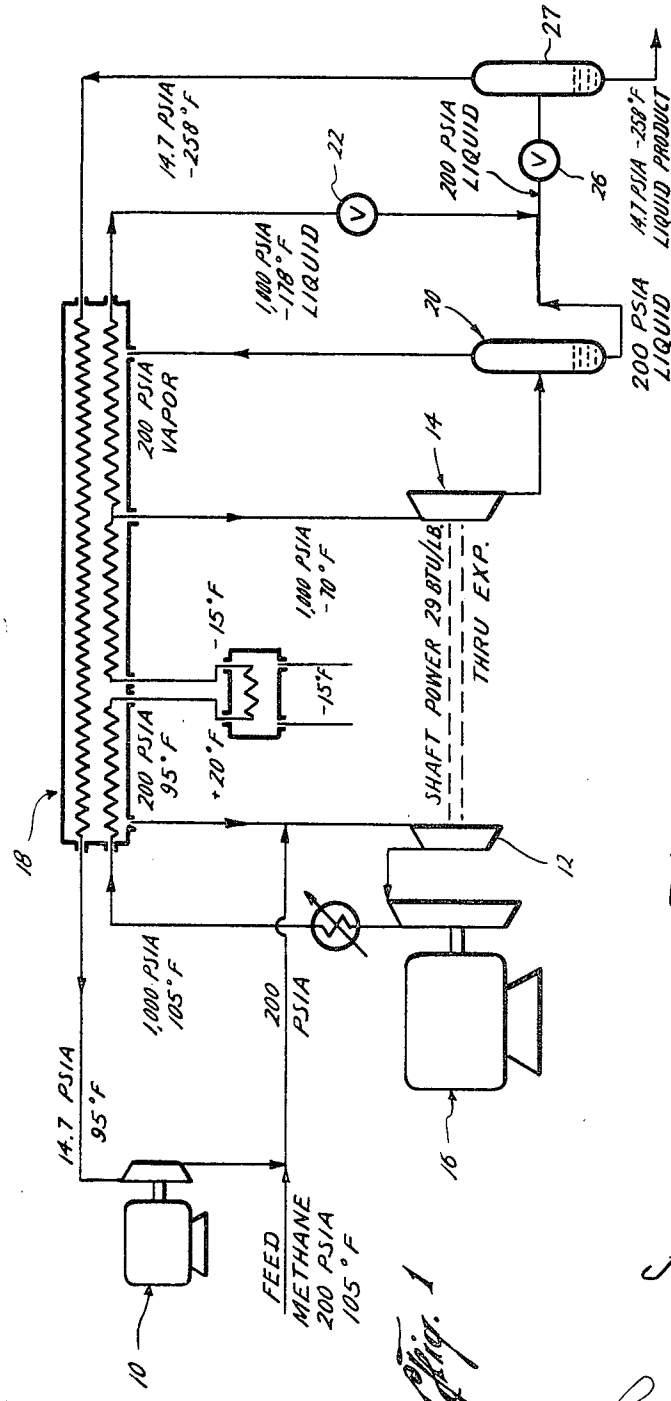


Fig. 1

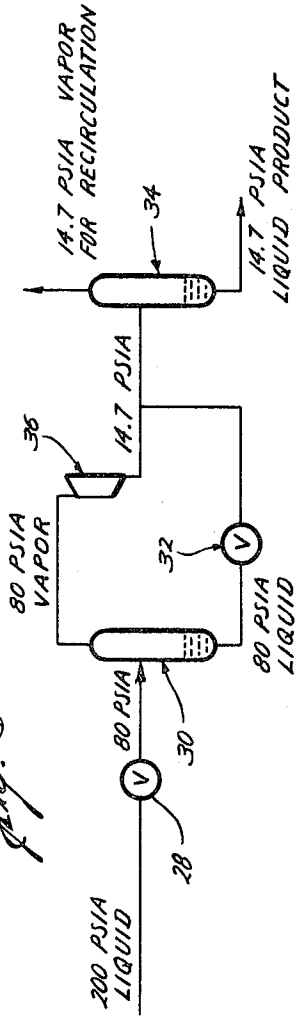


Fig. 3

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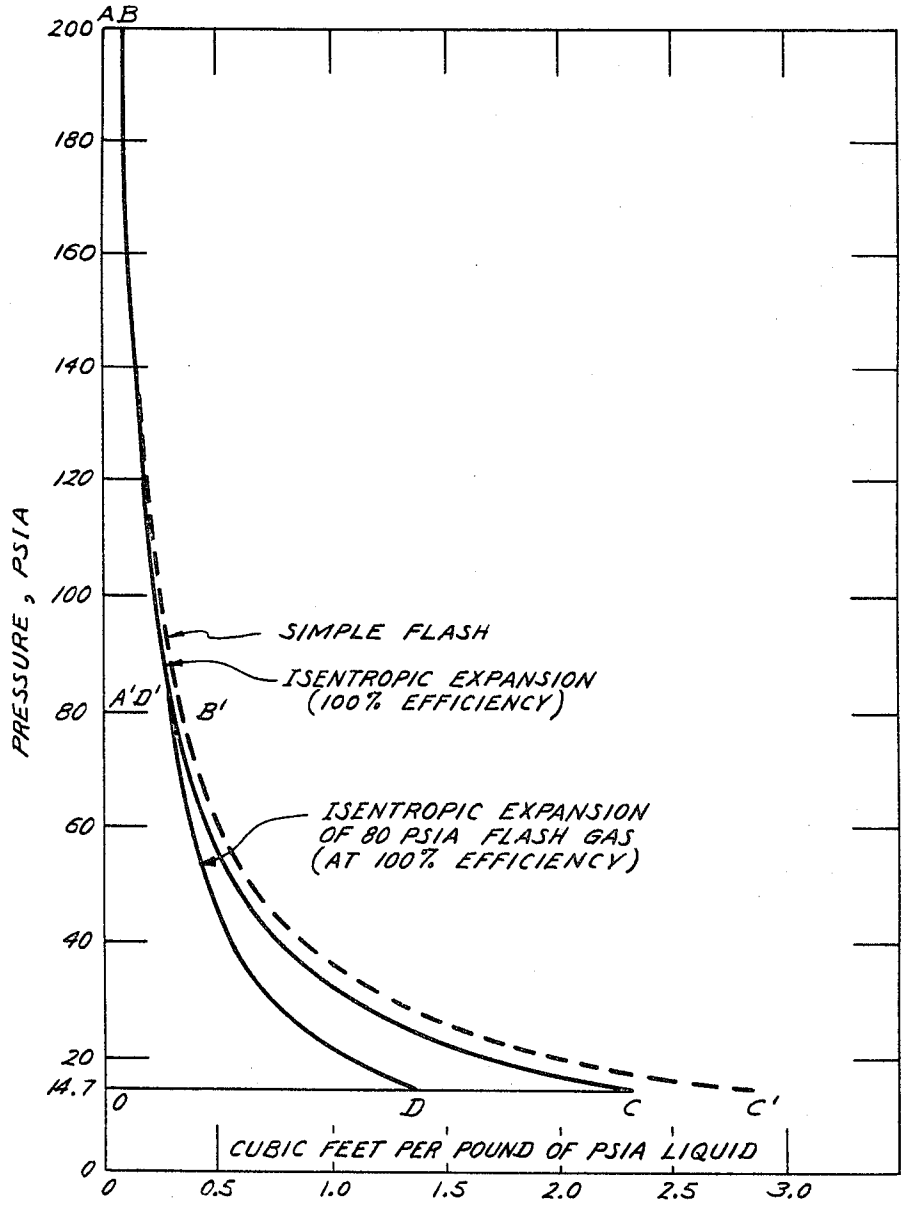


Fig. 2

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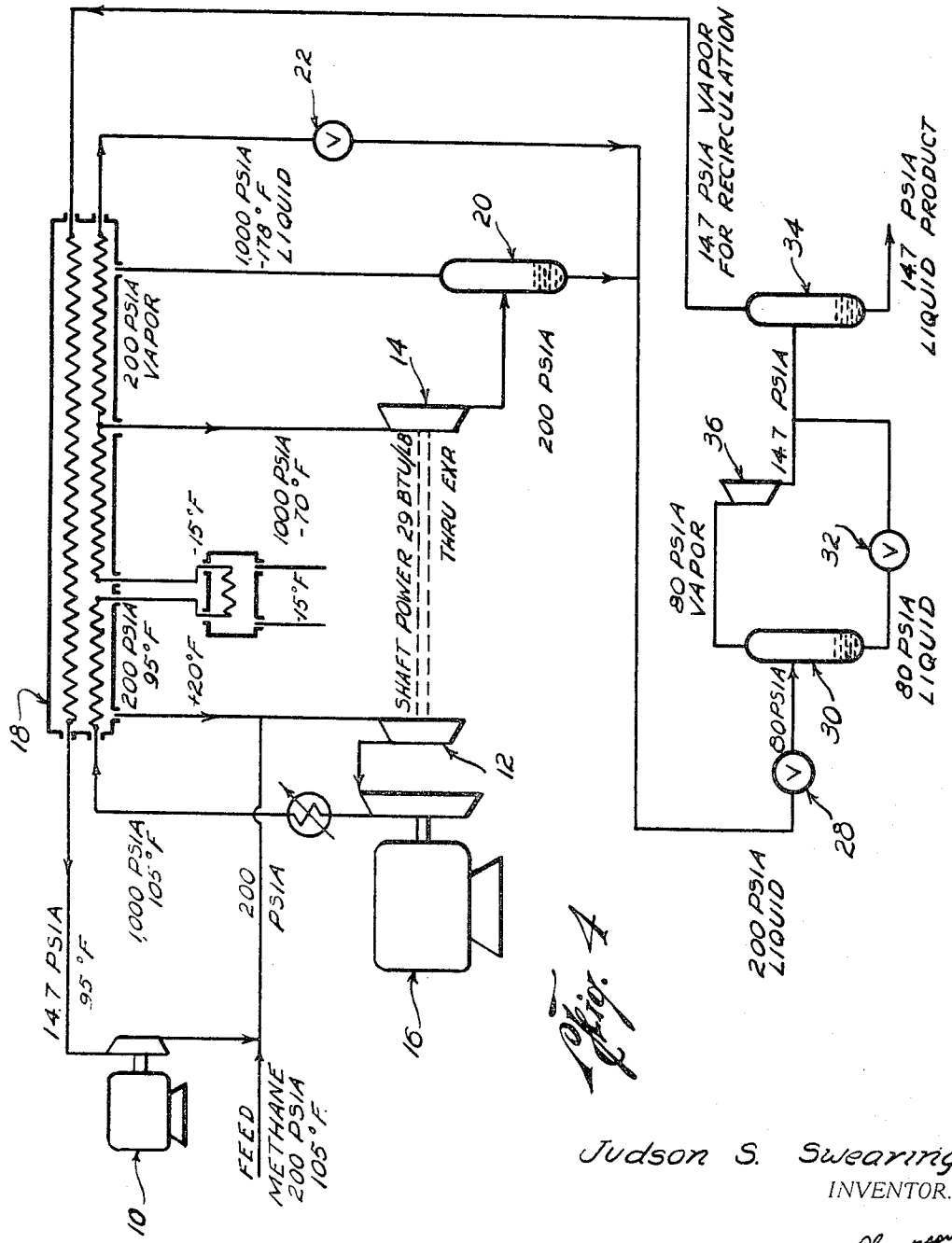


Fig. 4

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STAGED ISENTHALPIC-ISENTROPIC EXPANSION OF GAS FROM A PRESSURIZED LIQUEFIED STATE TO A TERMINAL STORAGE STATE

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Int. Cl. F25j 3/06

ABSTRACT OF THE DISCLOSURE

A first portion of a cooled natural gas stream is isentropically expanded causing partial liquefaction thereof and is thereafter separated. The separated liquid is combined with a second portion of cooled natural gas which has been liquefied and the combined liquid portion is isenthalpically expanded to an intermediate pressure and passed to a separator. Vapor from the separator is isentropically expanded while liquid bottoms are isenthalpically expanded, both portions being expanded to storage pressure, following which expansions they are combined, with the liquid therein being separated from the combined streams as liquid product.

This invention relates to a method of more efficiently liquefying gases. More particularly, it relates to a novel method of taking energy out of a cold stream of pressurized liquefied natural gas during the depressurization of the liquefied natural gas to atmospheric pressure.

In most of the processes used today to liquefy natural gas, the natural gas to be liquefied is first compressed and liquefied at a pressure considerably above that at which it is to be stored or used. This pressurized liquid (usually at its boiling point) then has its pressure released through an expansion orifice or valve commonly known as a Joule-Thomson nozzle to atmospheric pressure for storage in a cryostat. In such process, a portion of depressurized liquid vaporizes. This vapor is disengaged from the fluid and recycled or otherwise disposed of. The residual liquid constitutes the storable liquid derived from the process.

If, instead of isenthalpically expanding the pressurized liquefied natural gas through a Joule-Thomson nozzle to atmospheric pressure, the liquefied natural gas were expanded in an expansion engine so its expansion could take place isentropically, its energy of expansion could be removed as power and a heat equivalent to this power would be removed from the system. Various types of liquid turbines and piston expansion engines have been considered for this expansion. However, the presence of a comparatively dense liquid along with a light vapor makes turbine expansion of a saturated pressurized liquefied gas difficult and at low efficiency. Expansion of a saturated pressurized liquefied gas in a piston-type expansion engine is difficult because of the effect that the liquid has on the pistons, seals and valves. Accordingly, it is customary to flash the pressurized liquefied natural gas directly to atmospheric pressure through a Joule-Thomson nozzle, losing the expansion energy which could be conserved if the pressurized liquid was expanded isentropically.

I have found that, if, instead of flashing the pressurized liquefied natural gas isenthalpically to its terminal pressure, it is flashed to an intermediate pressure, the flash gas produced by the initial expansion can be separated from the remaining liquid, expanded isentropically and a large amount of the expansion energy may be recovered, plus an increase in liquid end product will be realized.

The intermediate flashing of the pressurized liquid is particularly useful in the liquefaction of methane, and a description of the liquefaction of methane will be used as an illustrative embodiment of the invention.

It is an object of this invention to increase the amount of liquefied gas that is retained when the pressure of the liquefied gas is reduced from process pressure to terminal pressure for storage.

It is another object of this invention to obtain useful work from the reduction of the pressure of liquefied natural gas, produced by a natural gas liquefication process, to a storage or terminal pressure.

It is an object of the present invention to provide in the process of liquefying natural gas the flashing of the pressurized liquefied natural gas to an intermediate pressure stage and then isentropically expanding the vapor, resulting from the flashing, to the terminal pressure stage to provide useful work and additional liquefied end product.

It is another object to provide in the liquefaction process of natural gas the flashing of the pressurized liquefied natural gas to a point above its terminal pressure, disengaging the vapor resulting from the flashing, and expanding such vapor isentropically in a turboexpander to its terminal pressure.

It is a further object of this invention to decrease the amount of liquefied gas that vaporizes when the pressure of the liquefied gas is reduced to a terminal pressure for storage by expanding the pressurized liquefied gas isenthalpically to an intermediate pressure, disengaging the flash vapor therefrom, isentropically expanding the intermediately disengaged vapor to a terminal pressure, and isenthalpically expanding the intermediately disengaged liquid to the terminal pressure.

It is still a further object in the liquefaction of a gas from a pressurized liquid state to a terminal storable state to isenthalpically expand the pressurized liquid in intermediate stages and, after each isenthalpic expansion, isentropically expand the resulting vapor to the next subsequent stage.

Other objects and advantages of this invention will become apparent from the following description taken in connection with the accompanying drawing, wherein is set forth an illustrative embodiment of the invention.

FIG. 1 is a flow diagram for the liquefaction of methane using compression, turboexpansion and mechanical refrigeration;

FIG. 2 is a pressure volume diagram, in which area represents work or expansion energy;

FIG. 3 is a flow diagram of the two stage depressurization taught by the present invention; and

FIG. 4 is a flow diagram of FIG. 1 modified to include the two stage depressurization of FIG. 3.

In general, liquefaction of natural gas is carried out either by cascaded mechanical refrigeration or by the use of turboexpanders or a combination of the two. FIG. 1 illustrates a flow diagram for methane liquefaction using compression, turboexpansion and mechanical refrigeration.

As can be seen, methane, at 200 p.s.i.a. and 105° F. is fed into the system. The feed stream is joined by a recycle stream of the same pressure from compressor **10** and an additional recycle stream of 200 p.s.i.a. from a heat exchanger **18**. The combined stream is compressed to 1000 p.s.i.a. in stages by compressor **12** operated from expander **14** and main compressor **16**. The compressed stream is then fed into the heat exchanger or mechanical refrigeration device **18** where it is cooled from the 105° F. temperature at which it enters. The larger portion of the stream is taken from the heat exchanger when it reaches minus 70° F. and passed through the turboexpander **14**.

The 1000 p.s.i.a., minus 70° F. stream is expanded to

200 p.s.i.a. and fed into a separator **20** where the liquid is drained off. The 200 p.s.i.a. vapor is recirculated back through the heat exchanger **18**. The energy derived from the expander **14** by the expansion is used to drive the compressor **12**.

The remaining small portion of the 1000 lb. stream is further cooled in the heat exchanger **18** to minus 178° F., at which point it becomes liquid. The pressurized liquid stream is released through a throttling valve **22** to 200 p.s.i.a. This liquid is combined with the liquid recovered from the separator **20** and the combined 200 p.s.i.a. stream flashed to atmospheric pressure through a Joule-Thomson nozzle **26** into a cryostat **27**.

The flash gas resulting from the Joule-Thomson reaction is recirculated back through the heat exchanger **18**, recovering its refrigeration and recompressed by the compressor **10** for recycling. The uncondensed portion of the 200 p.s.i.a. turboexpander discharge stream is also circulated back through the heat exchanger **18**, recovering its refrigeration and also recycled. The power generated by the expansion to the 200 p.s.i.a. level in expander portion **14** of the turboexpander is recovered by the compressor portion **12** operated in series with the main high-pressure compressor **16**.

This system has been designed to obtain efficient use of compression, turboexpansion and mechanical refrigeration in the liquefaction of methane. However, as a result of flashing the 200 p.s.i.a. liquid stream to atmospheric pressure through the Joule-Thomson nozzle **26**, there is a loss of energy. A more complete description of the efficiency of this system is contained in my paper which was published in the August 1966, issue of Hydrocarbon Processing.

Although it has been realized that it would be more desirable to isentropically expand the 200 p.s.i.a. stream to atmospheric pressure, whereby its energy of expansion can be removed as power and the heat equivalent of this power removed from the system, thereby condensing more liquid, no satisfactory solution has been developed. Although piston engines and liquid turbines have been considered, the presence of the comparatively dense liquid along with the light vapor makes the expansion difficult and, accordingly, has not been used.

However, it has been found that if the 200 p.s.i.a. cold stream of liquid methane is flashed only part way to its terminal pressure, such as to 80 p.s.i.a., instead of all the way to atmospheric pressure, then the amount of flash gas at the intermediate pressure is approximately in the order of one-half of total flash gas that would be produced at the terminal pressure. This intermediate stage flash gas may be disengaged and made available at the intermediate pressure for isentropic expansion. The isentropic expansion of this intermediate pressure gas can be carried out in a suitable turboexpander to recover a large amount of expansion energy. Expansion of this intermediate pressure flash gas through expansion ratios frequently encountered in such processes, such as 3 to 1 or 6 to 1, produces approximately 8.5% liquid from the exhaust of the turboexpander and are reasonable operating conditions for a turboexpander.

FIG. 2 is a pressure volume diagram in which area represents work or expansion energy and illustrates the amount of expansion energy recoverable by the isentropical expansion of 80 p.s.i.a. flash gas. The diagram ABCO represents the total expansion energy removable by 100% efficient isentropic expansion. Simple flashing or isenthalpic expansion follows the dashed line BB'C'. Separation of the liquid at B' and the isentropic expansion of the residual intermediate pressure gas to the discharge pressure of 14.7 p.s.i.a. follows the solid line D'D, and the area representing expansion energy is shown by the diagram A'D'DO, which in this illustration is approximately 55% of the area of ABCO. 80% or more of this 55% available energy may be recovered by the turboexpander.

Accordingly, FIG. 3 illustrates the equipment arrangement for practicing my invention and FIG. 4 illustrates the addition of my invention to a methane liquefaction process using compression, turboexpansion and mechanical refrigeration, such as is illustrated by the flow diagram of FIG. 1. The elements of FIG. 4 that are common to either FIG. 1 or FIG. 3 are designated by the same number in both figures.

Referring now to FIGS. 3 and 4, instead of flashing the 200 p.s.i.a. combined liquid stream through the Joule-Thomson nozzle **26**, as shown in FIG. 1, the 200 p.s.i.a. stream is released to an intermediate pressure of 80 p.s.i.a. by a valve **28**. The resultant stream is fed into separator **30** which disengages the 80 p.s.i.a. vapor from the liquid.

The 80 p.s.i.a. liquid recovered in the separator is flashed through a Joule-Thomson valve **32** to the atmosphere for delivery to cryostat **34** for storage. The disengaged 80 p.s.i.a. vapor is fed into a turboexpander **36** where it is isentropically expanded to atmospheric pressure. The exhaust from the turboexpander **36** which is now at 14.7 p.s.i.a. is combined with the 14.7 p.s.i.a. stream resulting from the isenthalpic expansion of the 80 p.s.i.a. liquid by the Joule-Thomson nozzle **32**. The combined stream is fed into cryostat **34**, which will store the liquid product and permit the disengagement of the super cooled 14.7 p.s.i.a. vapor which is recirculated in the system in the same manner as the vapor from cryostat **27** of FIG. 1.

In the process depicted by FIG. 1, if the pressurized liquid methane at its boiling point of 200 p.s.i.a. is released directly to atmospheric pressure (14.7 p.s.i.a.) through an orifice or expansion valve 67.8% of the stream would remain unvaporized.

It has been determined that if the 200 p.s.i.a. liquid stream were expanded to an intermediate pressure of 80 p.s.i.a. through a valve and the vapor disengaged and the disengaged liquid expanded through another valve to 14.7 p.s.i.a., the disengagement of the vapor from the last-mentioned expansion step would leave 68.5% liquid from the initial 200 p.s.i.a. liquid. Expansion through a high-efficiency turboexpander of the flash gas disengaged at the intermediate pressure will condense a portion of it equivalent to 2.6% of the initial liquid. These two quantities of expanded gas amount to 71.1% of the original pressurized liquid, thus resulting in a gain of 3.3% in product liquid. This is an actual increase in product yield of 3.3/67.8, which is equal to 4.88%.

Not only is more liquid product recoverble, but the energy developed by the expansion of the 80 p.s.i.a. vapor stream in the turboexpander can be utilized to compress some of the gas at some stage in the process, thereby further conserving energy.

Instead of having just one intermediate stage, flash gas may be disengaged at two or more successively lower intermediate pressures. In such case, each flash gas stream may be expanded, either in a separate expander or in an expander having intermediate gas introduction pressure points. Such a method would recover more power than the expansion of a single flash gas stream.

It has also been found that if the natural gas being expanded is not a pure substance nor a constant boiling mixture, that there are other advantages to the staged flashing. Flashing of such a liquid mixture to an intermediate pressure instead of to the final terminal pressure conserves liquid in such instances. Then the expansion of the intermediate flash gas in a turboexpander refrigerates it and condenses liquid from it. The liquid thus produced is richer in the lower-boiling constituents and thus increases the recovery of this liqiud.

From the foregoing it will be seen that this invention is one well adapted to attain all of the ends and objects hereinabove set forth, together with other advantages which are obvious and which are inherent to the apparatus.

It will be understood that certain features and suc-

combinations are of utility and may be employed without reference to other features and subcombinations. This is contemplated by and is within the scope of the claims.

As many possible embodiments may be made of the invention without departing from the scope thereof, it is to be understood that all matter herein set forth or shown in the accompanying drawings is to be interpreted as illustrative and not in a limiting sense.

The invention having been described, what is claimed is:

1. In the liquefaction process of natural gas to derive a liquid storable at a terminal pressure and wherein the natural gas is initially liquefied at a pressure substantially above said terminal pressure, the improvement which comprises: isenthalpically said pressurized liquid natural gas to an intermediate pressure below said elevated pressure but above said terminal pressure; disengaging the vapor resulting from the isenthalpic expansion to the intermediate pressure; isentropically expanding the disengaged vapor to said terminal pressure to further cool the vapor and cause a portion of the vapor to condense, and isenthalpically expanding the remaining liquid natural gas from the intermediate pressure to said terminal pressure.

2. The process set forth in claim 1 in which the terminal pressure is approximately atmospheric pressure.

3. The process set forth in claim 2 characterized in that the isenthalpic expansion of the liquid natural gas and the isentropic expansion of the vapor produced thereby is in multiple stages from the process pressure level to the terminal storage pressure level.

4. In a process for the liquefaction of methane to derive liquid methane storable at approximately atmospheric pressure, the improvement comprising compressing the methane to a predetermined elevated pressure, cooling said pressurized stream to the neighborhood of minus 70° F., isentropically expanding a large portion of the pressurized stream to approximately 200 p.s.i.a. and disengaging the liquid formed from said expansion; cooling and liquefying the remaining small portion of the stream at minus 178° F. after which it is isenthalpically expanded to approximately 200 p.s.i.a., combining the liquid derived from the isentropic expansion with liquid from the isenthalpic expansion, isenthalpically expanding the composite 200 p.s.i.a. stream to an intermediate pressure; disengaging flash vapor formed from said isenthalpic expansion at said intermediate pressure; isentropically expanding said intermediately disengaged vapor to the terminal pressure, and isenthalpically expanding said intermediately disengaged liquid to said terminal pressure, combining both expanded terminal pressure streams and disengaging the vapor from said combined terminal pressure streams.

5. The process set forth in claim 4 characterized in that the intermediate pressure to which the 200 p.s.i.a. stream is isenthalpically expanded is approximately 80 p.s.i.a.

6. The process set forth in claim 4 characterized in that the 200 p.s.i.a. stream is isenthalpically expanded at several stages between 200 p.s.i.a. and the terminal storage pressure and that after each isenthalpic expansion the vapor is disengaged and isentropically expanded to the succeeding lower isenthalpic expansion pressure.

7. A process for the liquefaction of natural gas, comprising compressing the natural gas to a predetermined elevated pressure, cooling said pressurized gas in a heat exchanger, isentropically expanding a large portion of the pressurized stream to a lower pressure that is well above atmospheric pressure, disengaging the liquid formed from said expansion; cooling and liquefying the remaining small portion of the natural gas stream after which it is isenthalpically expanded to the same pressure that the larger portion was expanded to isentropically, combining the liquid derived from the isentropic expansion with liquid from the isenthalpic expansion, isenthalpically expanding the composite stream to an intermediate pressure between the lower pressure to which the two portions were initially expanded and atmospheric pressure; disengaging flash vapor formed from said isenthalpic expansion at said intermediate pressure; isentropically expanding said intermediately disengaged vapor to a terminal pressure, and isenthalpically expanding said intermediately disengaged liquid to said terminal pressure, combining both expanded terminal pressure streams of isentropically expanded vapor and last mentioned isenthalpically expanded liquid and placing liquid from said isentropic and isenthalpic expansions to terminal pressure in storage at said terminal pressure.

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