

[54] **SYSTEM FOR RELIQUEFYING BOIL-OFF VAPOR FROM LIQUEFIED GAS**

[75] Inventor: Terry Wayne Delahunty, Plainfield, Ill.

[73] Assignee: Chicago Bridge & Iron Company, Oak Brook, Ill.

[22] Filed: Dec. 1, 1971

[21] Appl. No.: 203,729

[52] U.S. Cl. .... 62/54

[51] Int. Cl. .... F17c 13/00

[58] Field of Search ..... 62/51, 52, 53, 54, 62/55; 55/88, 89; 220/85 VR, 85 VS

[56] **References Cited**

**UNITED STATES PATENTS**

|           |        |                    |         |
|-----------|--------|--------------------|---------|
| 2,467,413 | 4/1949 | Wildhack .....     | 62/55 X |
| 2,632,302 | 3/1953 | Steele .....       | 62/55   |
| 2,944,405 | 7/1960 | Basore et al. .... | 62/54   |
| 3,191,395 | 6/1965 | Maher et al. ....  | 62/54   |
| 3,302,418 | 2/1967 | Walter .....       | 62/52   |

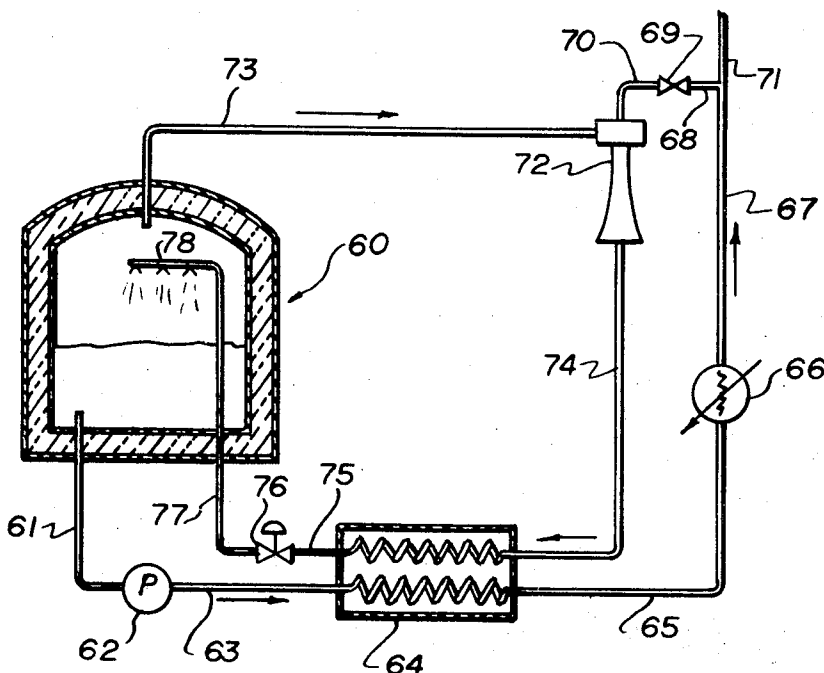
Primary Examiner—Meyer Perlin  
Assistant Examiner—Ronald C. Capossela  
Attorney—Charles J. Merriam et al.

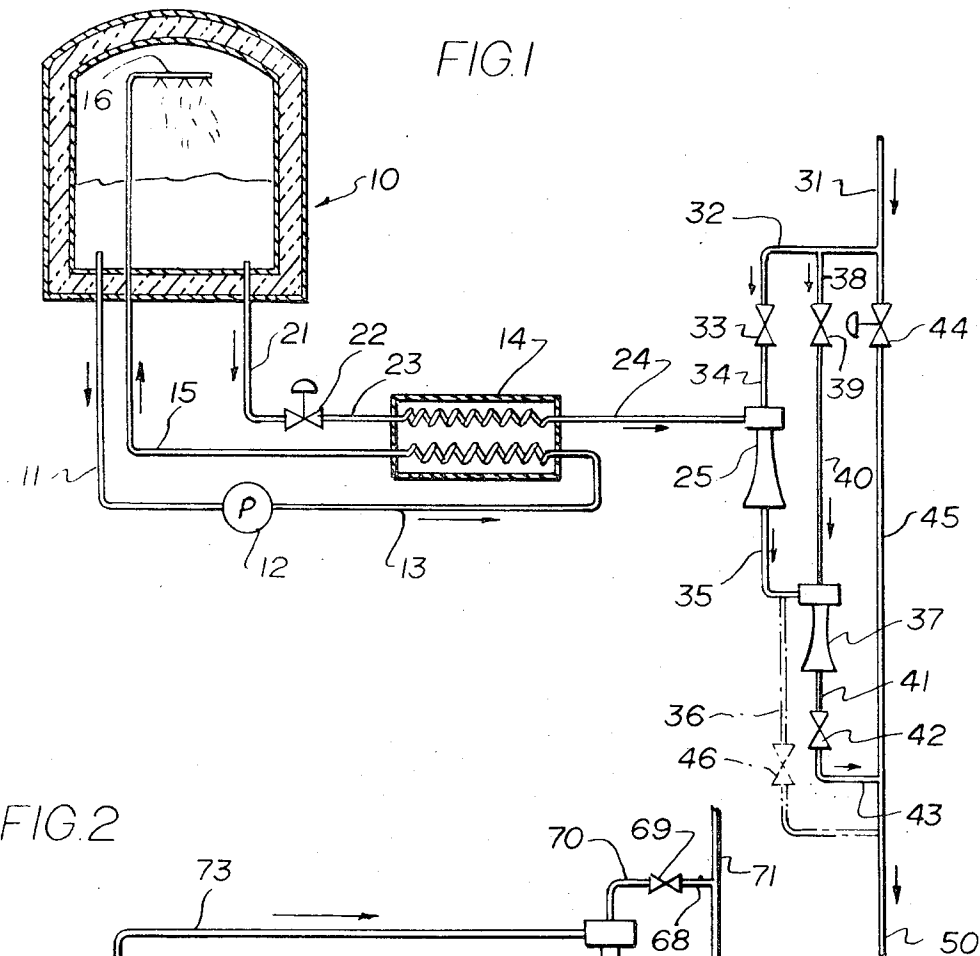
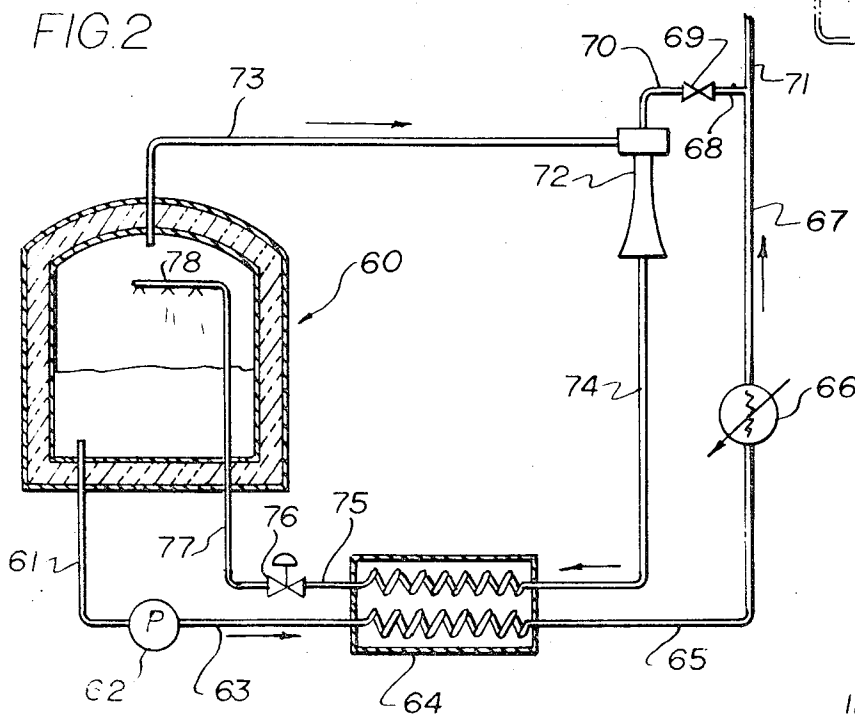
[57] **ABSTRACT**

Apparatus and processes for recondensing boil-off vapor from an insulated storage tank containing a liquefied gas, such as liquefied natural gas, so that it continues to comprise a part of the stored liquefied gas.

Boil-off vapor is recondensed by refrigeration obtained from expansion of a liquefied gas stream withdrawn from the storage tank. The expanded stream, as a vapor, can be pressurized by feeding it to the suction side of an ejector to which a high pressure gas is fed to supply the motive force. Alternatively, a vapor stream derived from the stored liquefied gas can be fed to a venturi ejector as the motive force to pressurize boil-off vapor fed from the storage tank to the suction side of the ejector. The combined stream from the ejector, after being refrigerated by the withdrawn liquefied gas stream, is expanded to the tank vapor space to cool the tank contents. Under either system, liquefied gas stored at about atmospheric pressure can be vaporized and distributed at a pressure greater than atmospheric pressure.

9 Claims, 2 Drawing Figures





64 INVENTOR.  
TERRY WAYNE DELAHUNTY  
BY *Merriman, Marshall, Shapiro &  
Klose.* ATTORNEYS.

# SYSTEM FOR RELIQUEFYING BOIL-OFF VAPOR FROM LIQUEFIED GAS

This invention relates to apparatus and processes for storing liquefied gases and the subsequent vaporization thereof.

A considerable number of normally gaseous materials are converted to their liquid state for storage and shipping because liquid form occupies much less space than the vapor. Some of the gases which are liquefied for this reason are natural gas, ethane, propane, butane, oxygen, nitrogen and hydrogen.

While high boiling liquefied gases can be stored practically in noninsulated tanks or containers it is not practical to store large volumes of the low boiling or cryogenic liquids in such tanks. Heat leak into the tank would be fast and would raise the temperature of the liquid to ambient temperature. To maintain the product liquid at ambient temperature would require very high pressures and tank walls sufficiently thick to withstand the necessary pressures. Large storage tanks with thick walls would be very expensive and difficult to construct. It is more feasible to store the liquefied gas at a temperature which has a vapor pressure at or about atmospheric pressure because the tank then need only be able to withstand the hydrostatic liquid load plus a small internal vapor pressure. However, to maintain the liquid at such low temperatures the tank must be suitably insulated to keep heat leak under control. Heat leak nevertheless takes place and boil-off vapor forms in the vapor space of the tank. Boil-off vapor refers to the vapor resulting from the addition of heat to an equilibrium mixture of liquid and vapor. Since the storage vessel is at constant pressure and volume, and since the volume occupied by the vaporized portion of the liquid is considerably greater than the volume occupied by the liquid portion prior to its vaporization, the majority of the vaporized liquid must either be removed from the tank or be recondensed to liquid.

While boil-off vapor can be conducted to a distribution line for use, this is often undesirable because it can have a composition different than that of the stored liquefied gas. This is particularly so in the case of a multicomponent stored product such as liquefied natural gas which can contain, besides methane, appreciable quantities of liquefied ethane, propane, butane and other liquids higher boiling than methane. The boil-off vapor in such instances will not be exactly like that of vapor formed by vaporizing an aliquot of the liquefied gas. The effect of heat leak into a liquefied multicomponent product preferentially vaporizes those components having the lower boiling points. If the boil-off vapors are removed from the storage vessel, the composition of the stored liquid and vapor necessarily must change, going from a mixture rich in low boiling components to a mixture rich in high boiling components. Accordingly, to supply a standard composition to a distribution line it is advisable to remove liquefied gas from the tank, vaporize the liquefied gas and feed the vapor so formed to the distribution line rather than boil-off vapor because this minimizes, even though it may not necessarily completely eliminate, composition change. This requires, however, that the inevitable boil-off vapor be disposed of or processed in a way which is compatible with such a system. It also requires that a withdrawn liquefied gas stored at atmospheric pressure be vaporized and brought to a pressure greater than at-

mospheric pressure to be transported in a distribution line.

According to the present invention, there are provided apparatus and processes for recondensing boil-off vapor from an insulated storage tank containing a liquefied gas so that it continues to comprise a part of the stored liquefied gas. The boil-off vapor is recondensed by utilization of refrigeration obtained from expansion of a liquefied gas stream withdrawn from the storage tank containing the same. The resulting expanded stream, as a vapor, can be pressurized by feeding it to the suction side of an ejector to which a high pressure gas is fed to supply the motive force. Alternatively, a vapor stream derived from the stored liquefied gas can be fed to a venturi ejector as the motive force to pressurize boil-off vapor fed from the storage tank to the suction side of the ejector. The combined stream from the ejector after being refrigerated by the withdrawn liquefied gas stream, can be expanded to the tank vapor space to cool the tank contents. Under either system, liquefied gas stored at about atmospheric pressure can be vaporized and distributed at a pressure greater than atmospheric pressure. This thus makes the systems especially useful in respect to liquefied natural gas and other liquefied gases stored at about atmospheric pressure.

In one embodiment of the invention, there is provided apparatus comprising an enclosed insulated storage tank for a liquefied gas, means for removing liquefied gas from the storage tank, feeding it through a heat exchanger to be cooled and delivering the cooled liquefied gas to the vapor space of the tank, and means for removing liquefied gas from the storage tank, expanding it and passing it as a refrigeration stream through the heat exchanger to provide refrigeration thereto. There can also be included means for feeding the refrigeration stream from the heat exchanger to the suction side of a venturi ejector, and means for supplying a high pressure gas to the ejector.

According to the same embodiment of the invention, there is provided a process which comprises removing a stream of liquefied gas from a storage tank and expanding it to a low pressure cold stream, removing a second stream of liquefied gas from the storage tank and passing it in heat exchange relationship with the cold first stream to cool said second liquefied gas stream, returning the cooled second liquefied gas stream to the vapor space of the storage tank to cool the tank contents including effecting at least partial condensation of boil-off vapor, and feeding the now warmed low pressure first stream to a distribution line, or advisably feeding it into inspiration or suction communication with a venturi ejector while feeding a high pressure third stream of gas through a venturi ejector to inspire and pressurize the low pressure vapor from the first stream and admix therewith to form an exit stream. The exit stream, if desired, can be passed to, and inspired through, a second venturi ejector by passage of part of the third stream of gas therethrough.

According to a second embodiment of the invention, there is provided apparatus comprising an enclosed insulated storage tank for a liquefied gas, means for removing liquefied gas from the storage tank, feeding it through a heat exchanger as a source of refrigeration, and delivering it as a high pressure vapor to the motive power inlet side of a venturi ejector, means for removing boil-off vapor from the storage tank and delivering

it to the suction side of the ejector, means for receiving the pressurized vapor from the ejector, passing it through the heat exchanger to cool it and condense it to a liquid and means for receiving the condensed liquid from the heat exchanger, expanding it and delivering the stream to the vapor space of the tank to cool the tank contents.

The same second embodiment of the invention provides a process which comprises removing a boil-off stream of vapor from a storage tank and feeding it into suction or inspiration communication with a venturi ejector, removing a stream of liquefied gas from the storage tank and passing it through a heat exchanger to provide refrigeration therein, feeding at least part of the stream from the heat exchanger in the form of a high pressure vapor through the venturi ejector as the motive force to pressurize the inspired boil-off vapor and form a combined warm vapor stream thereof, feeding the combined warm vapor stream through the heat exchanger to condense said stream to a cold liquid stream, and expanding the cold liquid stream and feeding it to the vapor space of the tank to absorb heat from the tank contents. The part of the refrigeration stream from the heat exchanger that is not fed to the venturi ejector can be fed as a vapor to a distribution line.

Under both of the described embodiments, complete recondensation of boil-off vapor requires that the total heat absorbed by the liquid spray counteract or equal the heat leak into the storage vessel.

It will be noted in the first embodiment of the invention that the ejector motive power is supplied by a stream not associated with the stored liquid, and that in the second embodiment the ejector motive power is from an auxiliary stream derived from the stored liquid.

The embodiments of the invention as described are particularly useful in conjunction with the storage of natural gas.

Ejectors being well known in the art as seen in Riet-dejk U.S. Pat. No. 3,464,230, will not be described in detail herein.

The invention will now be described further in conjunction with the attached drawings in which:

FIG. 1 is a schematic illustration of one embodiment of the invention in which the liquefied gas withdrawn for refrigeration to cool the tank contents, including boil-off vapor, is subsequently pressurized and fed to a distribution line; and

FIG. 2 is a schematic illustration of another embodiment of the invention for cooling the tank contents in which the liquefied gas withdrawn for refrigeration is subsequently used, at least in part, to pressurize withdrawn boil-off vapor.

With reference to FIG. 1, insulated storage tank 10 is of conventional construction and comprises inner and outer metal shells separated by insulating material. Conduit 11 communicates with the inside of tank 10 and with pump 12 for removing liquefied gas from the tank. Conduit 13 communicates with pump 12 and heat exchanger 14. Liquefied gas is fed to the heat exchanger by conduit 13 where it is cooled and from which it is fed by conduit 15 to the vapor space of tank 10. Conduit 15 communicates with spray head 16 from which the cooled liquefied gas is sprayed into the vapor space of the tank to absorb heat which leaks into the tank.

Also as shown in FIG. 1, conduit 21 communicates with the inside of tank 10 and with expansion valve 22

and is used to withdraw liquefied gas from the tank. The liquefied gas is conveyed from valve 22 by conduit 23 to heat exchanger 14 to supply refrigeration thereto. The warmed, low pressure vapor is removed from heat exchanger 14 by conduit 24 and can be disposed of as desired. It is advisable, however, to feed the low pressure vapor by conduit 24 to the suction or inspiration side of venturi ejector 25 to be pressurized.

Conduit 31, which can be a gas transmission line, conveys a high pressure gas stream to conduit 32, through valve 33 to conduit 34 and from it to ejector 25 to provide the motive power to pressurize the low pressure vapor supplied by conduit 24. Conduit 35 receives the combined gas stream from ejector 25 and can distribute it to any location desired, such as to line 50 by conduit 36 shown in phantom. Advisably, conduit 35 communicates with the suction side of second ejector 37. High pressure gas from conduit 31 is directed to conduit 38, through valve 39 to conduit 40 and then to ejector 37 to provide the motive power. The combined gas stream leaves the ejector 37 by conduit 41, at a pressure higher than in conduit 35, is passed through valve 42 to conduit 43 and by it to distribution line 50.

While the described ejector system is in operation, valve 44 can be closed or throttled to regulate gas flow from conduit 31 to conduit 45 and from it to distribution line 50. Similarly, when the entire ejector system is out of use, valves 33, 39, 42 and 46 can be closed. Also, if only ejector 25 is in operation, valves 39 and 42 can be closed and valve 44 closed or throttled as appropriate. Valve 44 could be left open, or partly open, to supply sufficient gas to distribution line 50 to meet customers needs if the amount of gas from conduits 35 and 43 is inadequate alone for this purpose.

The system of FIG. 1 is particularly useful where liquid natural gas liquefaction and storage facilities are both built along pipeline sites where a natural gas stream is expanded from a high main pressure to a customer distribution low pressure line. During periods when the liquefaction plant is not operating, the energy of the expansion process from the high pressure transmission gas is available and can be economically used to operate the ejector and overcome storage tank heat leak. Also, the expansion ratio and flow rate from peak shaving use of the stored liquefied gas is generally sufficient to operate the ejector.

The use of ejectors in the system is initially less costly than conventional compressors and operating costs are lower. Ejectors also require little servicing since they have no moving parts.

FIG. 2 illustrates another embodiment of the invention. Insulated tank 60 is of conventional type for storing a liquefied gas at about atmospheric pressure. Conduit 61 communicates with the interior of tank 60 and pump 62. A stream of liquefied gas is pumped from tank 60, by means of conduit 61 and pump 62, and is sent by conduit 63 to heat exchanger 64 to provide refrigeration. The warmed liquefied gas leaves the heat exchanger by conduit 65 and is fed to heater 66 where it is warmed and vaporized. From heater 66 the warmed but high pressure vapor is fed to conduit 67. Part of the high pressure vapor is fed from conduit 67 to conduit 68 and part to transmission or distribution line 71. The high pressure gas is fed by conduit 68, through valve 69 to conduit 70 and by it to venturi ejector 72 to provide the ejector motive power thereto.

Conduit 73 communicates with the vapor space of tank 60 and the suction or inspiration side of ejector 72 to supply the low pressure boil-off vapor thereto.

The discharge of the ejector, which contains both the compressed boil-off vapors and the motive stream vapor, is fed to conduit 74 and by it to heat exchanger 64 where the vapor is condensed. The condensed vapor or liquid stream is conveyed from heat exchanger 64 to conduit 75 and by it to expansion valve 76. The liquid is expanded through valve 76 to a pressure sufficient to overcome hydrostatic pressure and frictional resistance in conduit 77 and spray head 78. The liquid spray from spray head 78 absorbs heat from the vapor space and the liquefied gas stored in the tank.

The embodiment of FIG. 2 is useful where the base load plant supplies a liquid stream according to customer demand. When the available refrigeration from the customer demand stream is sufficiently large to condense both the boil-off vapor and the ejector motive stream, the application of this system is possible.

It should be understood that the liquid fed to the vapor space of the tanks in each embodiment of the invention need not be sprayed therein. The cooling liquid can be dispersed in the vapor space by other means, such as the use of splash plates, berle saddles or other means.

The following examples are presented to illustrate, but not limit, the invention.

#### Example 1

In the embodiment shown in FIG. 1, tank 10 stores liquefied natural gas at  $-258^{\circ}\text{F}$  and 15.3 psia. By conduit 11, 185 gallons per minute of liquefied natural gas are withdrawn and pumped through heat exchanger 14. After leaving the heat exchanger, the cooled liquefied natural gas at 25 psia and  $-270^{\circ}\text{F}$  is fed at 185 gallons per minute by conduit 15 to the vapor space of the tank.

Liquefied natural gas is removed by conduit 21, expanded through valve 22 and fed to conduit 23 at 8.5 psia and  $-270^{\circ}\text{F}$  at a rate of 1.03 million standard cubic feet per day. The vapor leaves the heat exchanger and is conveyed by conduit 24 at 8.5 psia and  $-270^{\circ}\text{F}$  at a rate of 1.03 million standard cubic feet per day to the suction side of ejector 25.

High pressure natural gas at 400 psia and  $60^{\circ}\text{F}$  at a rate of 1.47 million standard cubic feet per day is fed by conduit 34 to ejector 25. High pressure natural gas at 400 psia and  $60^{\circ}\text{F}$  is fed at a rate of 4.64 million standard cubic feet per day by conduit 40 to ejector 37.

The combined gas streams, with valves 44 and 46 closed, fed to conduit 43 is at 35 psia and  $-20^{\circ}\text{F}$  and flows at a rate of 7.14 million standard cubic feet per day.

#### Example 2

The embodiment of FIG. 2 can be operated under the following specific conditions although other conditions can obviously be used.

Liquefied natural gas at  $-258^{\circ}\text{F}$  and 15.3 psia in tank 60 is withdrawn by conduit 61 at  $-258^{\circ}\text{F}$  and 20 psia at a rate of 40 million standard cubic feet per day. The liquefied natural gas leaves pump 62 and by conduit 63 is conveyed at 600 psia and  $-258^{\circ}\text{F}$  at 40 million standard cubic feet per day to heat exchanger 64. The liquid stream leaves the heat exchanger at 600 psia and  $-235^{\circ}\text{F}$  at a rate of 40 million standard cubic feet per day

and is conveyed by conduit 65 to heater 66 where it is vaporized. Conduit 67 feeds the vapor at 600 psia and  $60^{\circ}\text{F}$  at a rate of 40 million standard cubic feet per day. Part of the vapor stream from conduit 67 is directed to conduit 68 at 600 psia and  $60^{\circ}\text{F}$  at a rate of 2.1 million standard cubic feet per day of gas, and part is directed to line 71 at 600 psia and  $60^{\circ}\text{F}$  at a rate of 37.9 million standard cubic feet per day.

Boil-off vapor is removed from the tank by conduit 73 at 15 psia and  $-258^{\circ}\text{F}$  at a rate of 1,000,000 standard cubic feet per day and is fed to the suction side of ejector 72. The combined vapor stream is fed by the ejector to conduit 74 which feeds the vapor at 40 psia and  $-110^{\circ}\text{F}$  at a rate of 3.11 million standard cubic feet per day to heat exchanger 64. After leaving the heat exchanger the condensed stream is expanded through valve 76 and the liquid is fed at 40 psia and  $-258^{\circ}\text{F}$  at a rate of 3.11 million standard cubic feet per day to spray head 78 from which it is sprayed into the vapor space of the tank to cool the contents.

The foregoing detailed description has been given for clearness of understanding only, and no unnecessary limitations should be understood therefrom as modifications will be obvious to those skilled in the art.

What is claimed is:

1. A process which comprises:

removing a boil-off stream of vapor from an insulated storage tank and feeding it into inspiration communication with a venturi ejector;

removing a stream of liquefied gas from the storage tank, pumping it to a high pressure and passing it through a heat exchanger to provide refrigeration therein;

feeding at least part of the stream from the heat exchanger in the form of a high pressure vapor through the venturi ejector as the motive force to pressurize the inspired boil-off vapor and form a combined warm vapor stream thereof;

feeding the combined warm vapor stream through the heat exchanger to at least partially condense said stream; and

expanding the at least partially condensed stream and feeding it to the vapor space of the tank to absorb heat from the tank contents.

2. A process according to claim 1 in which that part of the refrigeration stream from the heat exchanger that is not fed to the venturi ejector is fed as a vapor to a distribution line.

3. A process according to claim 1 in which the stream from the heat exchanger which provides refrigeration therein, is warmed and vaporized by passage through a heater and is then fed, at least in part, to the venturi ejector.

4. A process which comprises:

removing a boil-off stream of vapor from an insulated storage tank, compressing it and feeding it to a heat exchanger to be cooled;

removing a first stream of liquefied gas from the storage tank and passing it through the heat exchanger to provide refrigeration therein;

removing from the heat exchanger the at least partially condensed boil-off stream as a cold liquid stream;

expanding the at least partially condensed boil-off stream and feeding the resulting cold liquid stream to the vapor space of the tank to absorb heat from the tank contents;

removing from the heat exchanger the first stream of liquefied gas and further heating it; and feeding the now warmed first stream of liquefied gas as a vapor to a distribution line.

**5. In combination:**

an enclosed insulated storage tank for a liquefied gas; a first conduit communicating with the tank interior and a heat exchanger outside thereof for removing liquefied gas from the tank and sending it to the heat exchanger as a refrigeration stream;

a second conduit communicating with the heat exchanger and a venturi ejector for removing the refrigeration stream therefrom and sending it as a high pressure vapor to the ejector;

a third conduit communicating with the vapor space of the tank and the suction side of the ejector to remove boil-off vapor from the tank;

a fourth conduit communicating with the exit side of the ejector and the heat exchanger for supplying a mixture of pressurized boil-off vapor and refrigeration vapor to the heat exchanger for cooling;

a fifth conduit communicating with the heat exchanger and an expansion valve for delivering the condensed liquid mixture of boil-off vapor and refrigeration vapor to the expansion valve; and

a sixth conduit communicating with the expansion valve and the tank vapor space for delivering the

liquid mixture thereto.

**6.** The combination of claim 5 in which the second conduit has a heater therein to vaporize the stream as it passes therethrough.

**7.** The combination of claim 5 in which a seventh conduit communicates with the second conduit for diverting part of the vapor stream to a distribution line.

**8.** The combination of claim 5 in which a pump is located in the first conduit.

**9. In combination:**

an enclosed insulated storage tank for a liquefied gas; means for removing liquefied gas from the storage tank, feeding it through a heat exchanger as a source of refrigeration, and delivering it as a high pressure vapor to the motive power inlet side of a venturi ejector;

means for removing boil-off vapor from the storage tank and delivering it to the suction side of the ejector;

means for receiving the pressurized vapor from the ejector, passing it through the heat exchanger to cool and at least partially condense it; and

means for receiving the at least partially condensed liquid from the heat exchanger, expanding it and delivering the stream to the vapor space of the tank to cool the tank contents.

\* \* \* \* \*

30

35

40

45

50

55

60

65