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[54] **ONE FLOW CASCADE CYCLE WITH BUFFER VOLUME BYPASS**

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[58] **Field of Search** 62/9, 11, 40

[56] **References Cited**

UNITED STATES PATENTS

3,212,276	10/1965	Eld	62/40
3,364,685	1/1968	Perret	62/11
3,418,819	12/1968	Grunberg	62/11
3,578,073	5/1971	Bosquain	62/40
3,593,535	7/1971	Gaumer	62/40

OTHER PUBLICATIONS

A. P. Kleemenko, One Flow Cascade Cycle, in Prog. in Refrig. Science and Technology, 1960, p. 34–37.

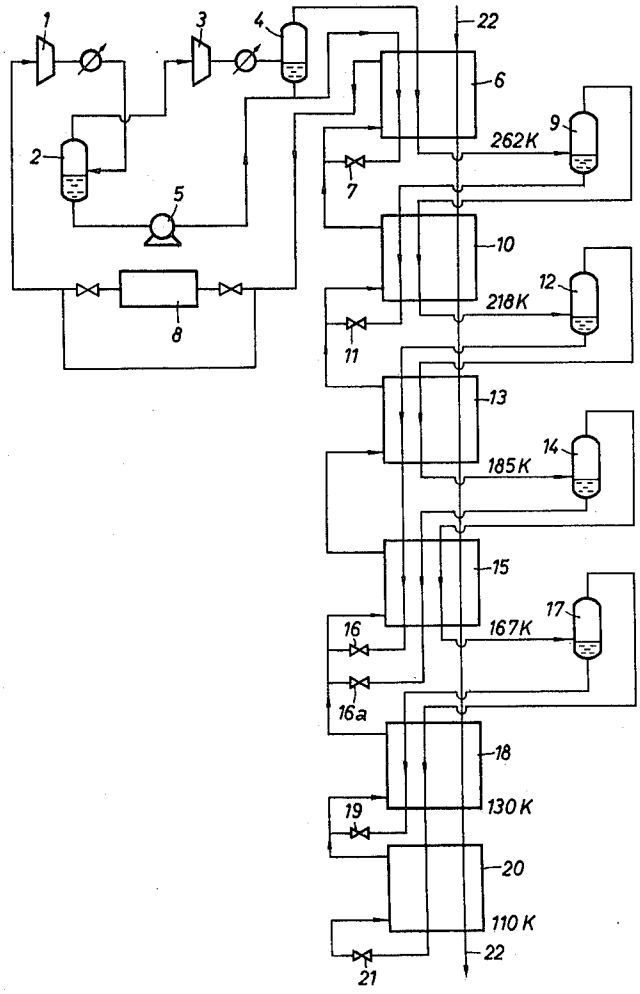
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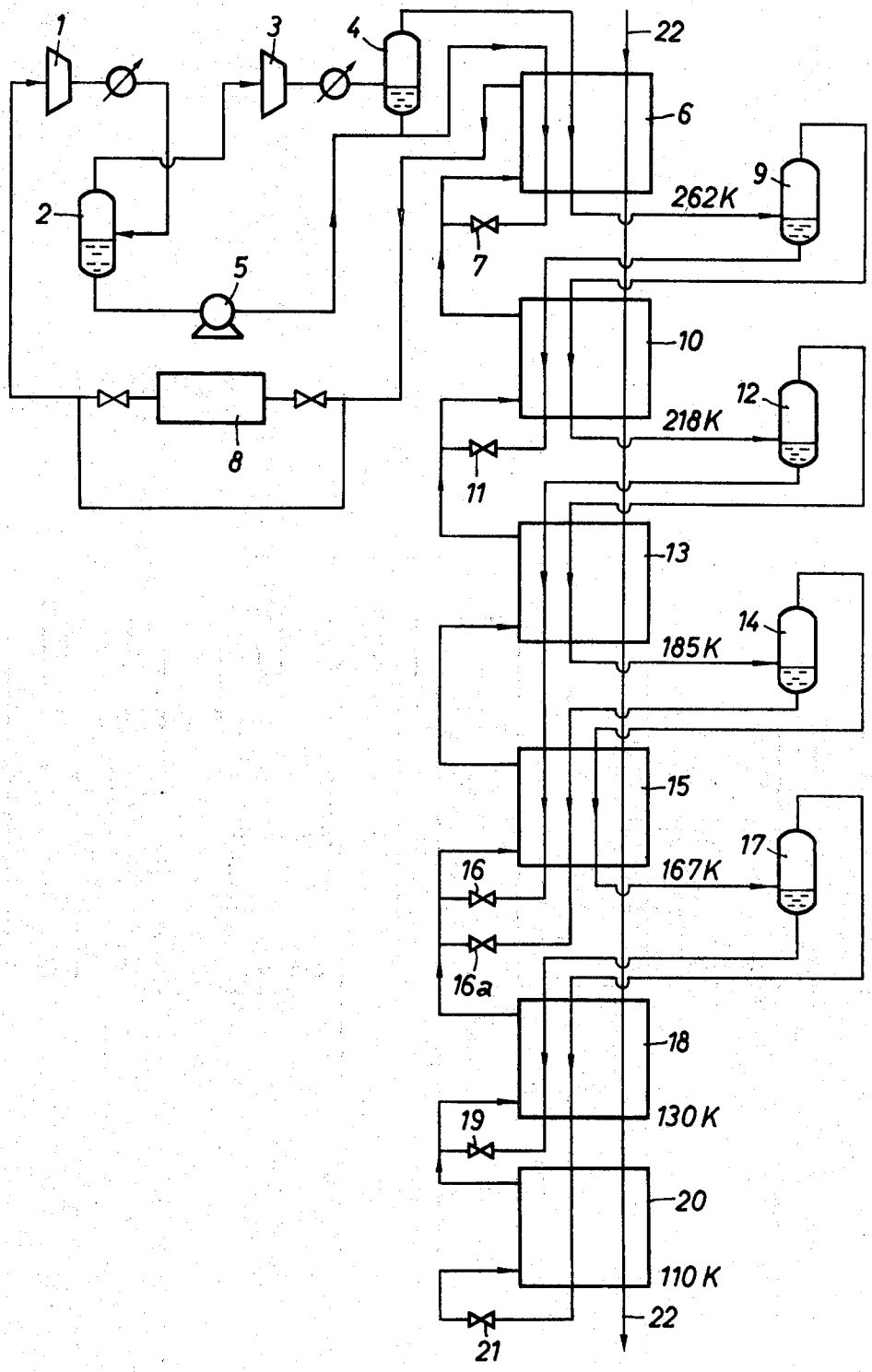
[57] **ABSTRACT**

In a system for the liquefaction of natural gas by a closed refrigeration cycle operated with a refrigerant mixture, wherein the refrigerant mixture is conducted through a hermetically sealed cycle comprising a cycle compressor, a low-pressure cycle section and a high-pressure cycle section, and wherein when the cycle compressor is cut off, the pressure in the low-pressure cycle section would build up to a pressure above the maximum design pressure of said low-pressure section in the absence of a pressure relief valve,

the improvement comprising providing sufficient buffer volume in said low-pressure section to compensate for said build-up in pressure, so said refrigerant mixture does not escape through said pressure relief valve.

2 Claims, 1 Drawing Figure




1
3
4
22
6
2
9
262K
7
5
10
12
218K
11
8
13
14
185K
15
17
16
167K
16a
18
130K
19
20
110K
22
21

ONE FLOW CASCADE CYCLE WITH BUFFER VOLUME BYPASS

BACKGROUND OF THE INVENTION

This invention relates to a process and apparatus for the liquefaction of natural gas wherein refrigeration is supplied by a closed refrigeration cycle operating with a mixture of refrigerants.

Cycles of the aforesaid type have become known by the name of "one flow cascade cycle." They exhibit the advantage over the classical cascade system, wherein several refrigerants are circulated in separate cycles and are condensed and vaporized therein at a respectively constant temperature, that only a single compressor is required, and that the refrigerating medium is vaporized and condensed at a floating temperature. Thus, with the "one flow cascade cycle," optimum temperature differences can be maintained in the heat exchangers by a calculated predetermined selection of the choice of the refrigerant composition and the intake and final pressures of the compressor.

Conversely, a negative aspect of the "one flow cascade cycle" of this invention is that the cycle gas composition must be constantly monitored and corrected, and to compensate for losses due to leakage through pressure relief valves, etc., each component of the mixture must be stored separately or produced during operation.

SUMMARY OF THE INVENTION

According to one aspect of this invention, there is provided an improved "one flow cascade cycle."

Other aspects and advantages will become apparent upon further study of the remainder of the specification and appended claims.

According to a principal aspect of this invention, the "one flow cascade cycle" is improved by providing means to maintain the refrigerant pressure at not more than the pressure maximally permissible for the cycle system at a time when the cycle compressor is cut off, said means also preventing discharge of the refrigerant mixture from the cycle.

Such means preferably comprises a relatively inexpensive buffer tank having a sufficient volume to insure that the pressure does not rise above design capacity. The elevation in pressure, which is to be compensated for by this buffer tank, stems especially from the fact that, when the plant is shut down, the liquid refrigerant fractions consisting of mixtures of cycle gas components (e.g., nitrogen, C_1- to C_5-paraffins), collected in the separators of the cycle system, gradually evaporate, but are no longer taken in by the cycle compressor. This rise in pressure, according to this invention, is in part compensated for by the volume of the buffer tank and in part absorbed by the parts of the plant in the cycle system. The low-pressure section of the plant must, therefore, be designed to operate at a pressure above the intake pressure of the cycle compressor. The buffer volume and the pressure which must be withstood by the portions of the plant into the cycle system are thus correlated so that no damage is caused by the expected pressure elevation when the plant is shut down. The larger the buffer volume is chosen, the lower are the requirements with respect to the pressure resistance of the plant. This result can easily be recognized from the general gas equation.

In case of pressure and temperature equalization the resulting pressure will be:

Case without buffer: $P_o = m_o R T Z_o/V_o$

Case with buffer: $P_m = (m_o + m_b) R T Z_m/V_o + V_b$

From these equations the equalizing pressures with and without buffer volume can be derived.

$$P_m/P_o = V_o/V_o + V_b \times Z_m/Z_o \times m_o + m_b/m_o$$

Since the buffer volume at normal compressor suction conditions contributes little to the mass content of the total system the factor $m_o + m_b/m_o$ approaches 1.

With the envisioned pressures for P_o and P_m the compressibility factors Z_o and Z_m do not differ significantly so that the resulting ratio Z_m/Z_o approaches also 1.

Thereby the ratio of the equalizing pressure with and without buffer volume is well represented by

$$P_m/P_o \cong V_o/V_o + V_b$$

P_o = Equalizing pressure without buffer
P_m = Equalizing pressure with buffer
m_o = Mass inventory without buffer
m_b = Mass inventory of buffer
V_o = Geometric volume of the total system without buffer
V_b = Geometric volume of buffer
Z_o = Compressibility factor at equilibrium pressure without buffer and temperature T of cycle gas
Z_m = Compressibility factor at equilibrium pressure with buffer and temperature T of cycle gas
R = General gas constant of cycle gas
T = Temperature

The invention thus offers the advantage that the refrigerant, when the compressor is shut down, need not be blown off via a pressure relief valve, so that losses of refrigerant caused during operation due to leakage are held to a minimum. Consequently, it is no longer necessary to store large quantities of the individual components of the components and/or to produce these components during operation. Any unavoidable trace losses can be replenished from bottles, but such losses are so small that a constant monitoring of the composition of the cycle gas mixture is unnecessary. In this way, the plant operates substantially service-free.

The time and location of when and where the buffer volume is introduced into the cycle can be varied. Thus, it is possible, for example, to insert the buffer tank in a bypass line of the cycle compressor and introduce the tank into the cycle only when the compressor is at a standstill. It is also advantageous to conduct the refrigerant mixture, before it is taken in by the compressor, through the buffer tank, i.e., to incorporate the buffer tank, while the refrigerant mixture is being circulated by the cycle compressor and refrigeration is being produced, into the cycle on the intake side of the compressor. In such a case, the expenditure with respect to switching elements and servicing is particularly low. Another suitable embodiment resides in connecting the buffer tank to a tap connected to the intake side of the cycle system.

In order to conduct the invention, it is not even absolutely necessary to provide a separate buffer tank. The required buffer volume can also advantageously be provided by dimensioning the shell space of the tubular heat exchangers pertaining to the low-pressure section

of the cycle system so that such shell space has the required buffer volume. This can be done, for example, by making the shell longer than the tube nest disposed on its interior. In case of plate-type heat exchangers, the same purpose can be achieved by enlarging the collecting members leading from the pipelines to the heat exchange cross sections. Instead of enlarging the heat exchangers, it is also possible to accomplish the same ends by enlarging the volume of the separators associated with the cycle system. A lowering of the liquid level in the separators to the minimum required for reasons of control technology has an analogous effect; this measure can be readily executed in the process of the present invention, because the leakage losses are extremely low, so that a lowering of the liquid level due to evaporating liquid for supplementing the lost cycle gas is of hardly any significance.

The plant for conducting the process of this invention is characterized in that the cycle system carrying the refrigerant mixture is hermetically sealed; means defining a buffer volume provided in the cycle system; and that the cycle system is designed for a pressure adapted to the buffer volume in such a manner that the refrigerant pressure cannot exceed the maximally permissible pressure when the cycle compressor is at a standstill. A pressure relief valve in the cycle system is undesirable in view of the leakage potential. The cycle system therefore is designed without relief valves venting to the atmosphere. Emergency relief capacity is provided by a bursting disk assuring a reliable gas tight seal.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The process and apparatus of this invention will be explained in greater detail below with reference to the attached schematic drawing.

As the cycle medium, 25,000 Nm^3 of a gaseous mixture is employed having, in general, for the liquefaction of natural gas, a composition about: 3–10 mole percent nitrogen; 25–50 mole percent of methane and ethane, respectively; and 0–20 mole percent of propane, butane, and pentane respectively. The refrigerating cycle described hereinbelow is operated with a particular gaseous mixture of about one third each of methane and ethane, while the remaining third is composed of approximately equal parts of nitrogen, propane, butane, and pentane. This cycle gas is compressed in the first compressor stage **1** from 5 atm. abs. to 14 atm. abs., then cooled with water, and thereafter conducted through the separator **2,** wherein a condensate is separated consisting of two thirds of pentane and also containing the lower-boiling hydrocarbons in accordance with their solubilities at the given partial pressure.

The cycle medium withdrawn from the separator **2** in the gaseous phase is compressed to 35 atm. abs. in the second compressor stage **3** and again cooled with water. During this step, a fraction is condensed which is comprised predominantly of pentane, and in addition to a small amount of methane, larger proportions of ethane, propane and butane. This fraction is separated from the gaseous phase in the separator **4**; fed to the warm end of the tubular heat exchanger **6** together with the condensate from separator **2,** brought to 35 atm. abs. by means of the pump **5**; subcooled therein to 262° K.; then expanded in valve **7** to the intake pressure of the first compressor stage, namely 5 atm. abs.; and then vaporized and warmed in the shell space of the exchanger **6,** and again taken in, via the buffer tank **8,** by the compressor. As seen from the drawing, the buffer tank may be bypassed during the time the compressor is on, and then inserted into the system when the compressor is shut off.

The proportion of the cycle medium from separator **4** remaining in the gaseous phase is likewise cooled in heat exchanger **6** to 262° K.; in this step, a liquid, half of which is ethane, is obtained as the condensate, which contains furthermore methane, propane, butane, and pentane in approximately equal parts, and additionally a small amount of nitrogen. This liquid is separated from the gaseous phase in the separator **9,** cooled in the tubular heat exchanger **10** to 218° K., expanded in valve **11** to 5 atm. abs., vaporized and warmed in the shell space of the exchanger **10,** and combined with the cycle medium which has been expanded in valve **7.**

The gaseous mixture from separator **9** is likewise cooled to 218° K. in the heat exchanger **10.** At this temperature, a liquid is condensed which contains primarily ethane and methane with nitrogen, propane, butane, and pentane being present in minor amounts. This liquid is separated from the gaseous phase in the separator **12,** subcooled to 167° K. in the heat exchangers **13** and **15,** and expanded in valve **16.**

The cycle medium leaving the separator **12** in the gaseous phase is further cooled to 185° K. in the heat exchanger **13** and then conducted through the separator **14,** wherein a liquid is collected comprised mainly of methane and the residual ethane. This liquid, just as the condensate coming from the separator **12** via the heat exchanger **13,** is subcooled to 167° K. in heat exchanger **15** and then expanded in valve **16***a*. The liquid is vaporized and warmed in the shell space of the heat exchangers **15** and **13** and is then combined with the liquid expanded in valve **11.**

The cycle medium withdrawn from the separator **14** in the gaseous phase is further cooled in the heat exchanger **15** to 167° K. During this step, a fraction is condensed containing primarily methane with only minor amounts of ethane as well as nitrogen. This fraction is separated in the separator **17,** subcooled to 130° K. in the heat exchanger **18,** expanded to 5 atm. abs. in the valve **19,** vaporized and warmed in the shell space of the heat exchanger **18,** and then admixed to the liquid exiting from valve **16.**

From separator **17,** a gaseous mixture is discharged which only contains the lowest-boiling cycle gas components: nitrogen and methane in approximately equal proportions. This mixture is liquefied in the heat exchangers **18** and **20** and also subcooled therein to 110° K., expanded in valve **21,** vaporized and warmed in the shell space of the heat exchanger **20,** and then further warmed and recompressed together with the remaining expanded fractions of the cycle medium.

The conduit system wherein the natural gas is cooled and liquefied is denoted by **22.** From the cold end of the exchanger **20,** about 6,000 Nm^3/h. of liquid natural gas can be withdrawn at a temperature of 110° K.

As demonstrated by the preferred embodiment, the cycle system is composed of a high-pressure section designed for the final compressor pressure, to which belong the conduit systems for cooling the pressurized cycle medium, as well as the separators and connection conduits; and of a low-pressure section comprised of the shell spaces of the tubular heat exchangers, the connecting conduits to the expansion valves and to the

intake side of the compressor, as well as the buffer tank. The volume of the entire cycle system comprising the high-pressure and low-pressure sections is 50 m^3. Of this volume, 40 m^3 pertains to the low-pressure section of which the volume of the buffer tank of 10 m^3, or 25 percent of the total volume of the low-pressure side.

Once the refrigerating medium, after shutdown of the compressor, has warmed to ambient temperature (up to about 50° C.), a pressure of 10 atm. abs. is ambient in the high-pressure section as well as in the low-pressure section of the cycle system. The low-pressure section is designed for an operating pressure of 10 atm. gauge, i.e., a pressure lying above the intake pressure of the compressor (5 atm. abs.). Thus, even when the plant is shut down, this arrangement makes certain that the hermetically sealed cycle system is not damaged by the gradually increasing pressure of the refrigerant. The frequency of compressor shut down varies with the operating mode of the liquefaction plant. In typical applications shut down may accure between once a week or once a year.

From the foregoing description, one skilled in the art can easily ascertain the essential characteristics of this invention, and without departing from the spirit and scope thereof, can make various changes and modifications of the invention to adapt it to various usages and conditions.

What is claimed is:

1. In a process for the liquefaction of natural gas by a closed "one flow cascade" refrigeration cycle operated with a refrigerant mixture, wherein the refrigerant mixture is conducted through a hermetically sealed cycle comprising a cycle compressor, a low-pressure cycle section and a high-pressure cycle section, and wherein when the cycle compressor is cut off, the pressure in the low-pressure cycle section would build up to a pressure above the maximum design pressure of said low-pressure section in the absence of a pressure relief valve,

the improvement comprising introducing sufficient buffer volume in said low-pressure section when the cycle compressor is cut off, to compensate for said build-up in pressure, so said refrigerant mixture does not escape from said cycle, and so that pressure relief valves venting to the atmosphere are not required, said buffer volume being bypassed during normal operation of the cycle compressor.

2. A process defined by claim **1**, wherein said low-pressure cycle section comprises shell spaces of tubular heat exchangers and conduits to expansion valves and to the intake side of the cycle compressor.

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