LNG STORAGE TANK VAPOR RECOVERY
BY NITROGEN CYCLE REFRIGERATION
WITH REFRIGERATION MAKE-UP
PROVIDED BY SEPARATION OF SAME
VAPOR

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ABSTRACT
Method and device of treatment of natural gas contained in storage tanks, for producing liquid nitrogen by extraction of nitrogen from the vapours resulting from the evaporation of said liquefied natural gas in said tanks, liquefaction of a portion of said extracted nitrogen and storage thereof for forming a reserve of cold.

18 Claims, 6 Drawing Figures
The present invention relates to a method of treatment of natural gas contained in a liquefied state in storage and/or transportation tanks, of the type consisting in producing liquid nitrogen by utilizing, to this end, the boil-off of the liquefied natural gas, the methane and higher-hydrocarbon fraction of which is simultaneously re-liquefied, as well as a device for carrying out said method, usable especially on board methane tankers or in land storage plants.

The invention aims at providing simple means for producing liquid nitrogen usable partly as a cold-producing fluid for the re-liquefaction of methane, and partly for sale.

The resulting simplification enables liquefaction units to be obtained which are sufficiently compact and economical to be used on board methane tankers or in liquefied-natural-gas land storage plants. To this end, the invention provides a method of treatment of natural gas contained in a liquefied state in storage and/or transportation tanks, of the type consisting in producing liquid nitrogen from the boil-off of the liquefied gas and characterized in that nitrogen is extracted from the vapours resulting from the evaporation of the liquefied natural gas contained in the said tanks, at least a portion of the extracted nitrogen is liquefied and the liquid nitrogen is stored as a reserve of cold.

After the liquefied natural gas has been unloaded, use is made of the said reserve of cold to pre-cool the tanks and fill them with an inert atmosphere before again filling the tanks with liquefied natural gas.

As compared with the known methane liquefaction methods comprising an indirect cycle using in particular nitrogen as a cold-producing fluid, the method of the present invention differs therefrom in that the nitrogen used in an open circuit as a cold-producing fluid is extracted from the evaporations of the liquefied natural gas conveyed in the tanks of methane tankers or stored in land reservoirs. One of the main advantages offered by the invention results from the fact that the nitrogen extracted from the liquefied natural gas is free from interfering impurities such as steam, carbon dioxide, sulphur dioxide, oxygen and so forth, which are present in the gases usually employed for the production of liquid nitrogen (atmospheric air or gases resulting from combustion).

Another advantage lies in the fact that the nitrogen extracted from the liquefied-natural-gas evaporation already has a temperature close to that of liquid methane, i.e. about -160°C under the usual conditions of transportation and storage of the liquefied natural gases. This low initial temperature of the nitrogen contained in the liquefied natural gas reduces the amount of cold necessary to liquefy the same and, in case of partial liquefaction of the available nitrogen, the nitrogen which is rejected to the atmosphere in a gaseous state supplies previously the frigories corresponding to its sensible heat, thus facilitating the reliquefaction of the nitrogen fraction entering the cycle.

This results in a substantial reduction of the refrigerating power which is necessary to enable the indirect cycle using nitrogen as a cold-producing fluid to ensure the re-liquefaction of the total amount of methane which is present in the or boil-off of the contents of the tanks of the methane tankers or the land storage plant.

According to another feature of the invention, the method of re-liquefaction of the methane vapours resulting from the evaporation of liquefied natural gas, with simultaneous extraction of nitrogen, consists in treating the liquefied-natural-gas vapours by way of cryogenic distillation or fractioning by bringing them into contact with a reflux liquid rich in nitrogen, so as to obtain gaseous nitrogen, on the one hand, and a condensed hydrocarbon mixture practically free from nitrogen, on the other hand, the latter then being returned into the liquefied-natural-gas tanks. The cold for the condenser of the distillation column is provided by the evaporation of the liquid nitrogen contained in a reservoir. The liquid-nitrogen vapours of the reservoir are mixed with the gaseous nitrogen extracted from the natural gas in order to be introduced into a nitrogen re-liquefaction cycle.

The invention is also characterized by a device for the re-liquefaction of liquefied-natural-gas vapours and simultaneous extraction of nitrogen, the said device comprising a column for the cryogenic distillation or fractioning of liquefied-natural-gas vapours, connected, on the one hand, to the liquefied-natural-gas tanks by a vapour supply conduit and by a re-boiler drum for the return of the said condensed hydrocarbon mixture to the said tanks, and, on the other hand, to a reflux drum placed in the said liquid-nitrogen reservoir, the said reflux drum comprising a return outlet to the said distillation column and a second outlet to the said nitrogen re-liquefaction cycle.

The invention therefore results in a highly profitable exploitation of, for instance, a methane tanker, for it makes it possible, by means of an insignificant energy make-up, to re-liquefy all the liquid-natural-gas evaporation while extracting simultaneously the nitrogen contained in the liquid-natural-gas vapours, and to thus form a liquid nitrogen reserve capable of providing high-potential cold which can be used on board the tanker for the pre-cooling of the tanks and the tank filling conduits, for preparing a further liquid-natural-gas cargo, or on land for all the known uses of liquid nitrogen.

Where the invention is applied to stationary land-storage tanks, it makes it possible not only to re-liquefy all the methane vapours resulting from the evaporation of the liquefied natural gas, to enrich the liquefied natural gas, but also to extract the nitrogen contained in the said natural gas and store the liquid nitrogen thus obtained. The nitrogen extracted from the natural-gas vapours is practically pure and free from interfering impurities, and can be sold at interesting prices.

The invention will be better understood and other objects, characteristics and advantages thereof will appear as the following description proceeds, with reference to the appended drawings given solely by way of example illustrating several forms of embodiment of the invention and wherein:

FIG. 1 is a general diagrammatic view of a plant according to the invention, applicable to a methane tanker or a stationary storage plant;

FIG. 1a is a simplified diagrammatic view of the same plant;

FIG. 2 is a general diagrammatic view of an alternative of embodiment of the invention;
FIG. 3 is a diagrammatic view of one exemplary embodiment of a compressor and a turbine used in the invention;

FIG. 4 is a view of another embodiment of a compressor and a turbine according to the invention;

FIG. 5 is a graphic representation of the nitrogen liquefaction and refrigeration circuit according to the invention.

In the exemplary embodiment of the invention illustrated in FIG. 1, a liquefied-natural-gas tank is shown at 1 and a liquid nitrogen reservoir is designated by the reference numeral 2. The liquid-natural-gas vapours are sucked by a blower 3 into a conduit 4 and are conveyed into a cryogenic distillation or fractioning column 5. The column 5 is connected, on the one hand, to a re-boiler drum 6 through a supply conduit 7, a liquefied natural-gas pump 8 and through a return conduit 9 for the liquefied-natural-gas vapours. On the other hand, the column 5 is connected to a reflux drum 10 placed within the liquid nitrogen reservoir 2, through a nitrogen vapour supply conduit 11, and a conduit 12 with a pump 13 for the return of liquid nitrogen into the said column.

The circuit of re-liquefaction of the liquefied-natural-gas vapours proceeding from the tank 1 is shown in thicker lines.

The gaseous nitrogen proceeding from the reflux drum 10 and resulting from the liquid-nitrogen evaporation obtained in the tank 2 is conveyed by the conduits 14 and 15 into the nitrogen liquefaction circuit. This circuit comprises a conduit 16 connected, on the other hand, to the conduits 14 and 15 and, on the other hand, to a blower 47 delivering into a series of heat exchangers 17, 18, 19 which are intended to heat the gaseous nitrogen, a multi-stage compressor 20 driven by a motor 21, a heat exchanger 22, using for instance water or any other suitable cooling fluid such as air, propane, ammonia, freon and so forth, serving to cool the nitrogen compressed in the compressor 20.

The compressed nitrogen then re-passes through the coil 23 of the heat exchanger 19, the coil 24 of the heat exchanger 25, and then the coils 26, 27, 28 of, respectively, the heat exchanger 18, the re-boiler drum 6 and the heat exchanger 17. The nitrogen thus cooled passes through the coil 29 of a heat exchanger 30 before being introduced into cold separators 31 and 32. The liquid nitrogen collected at the bottom of the cold separator 31 is conveyed through a conduit 33 into the cold separator 32, and the liquid nitrogen collected in this second separator returns through a conduit 34. The gaseous nitrogen contained in the first cold separator 31 is conveyed through a conduit 35 into an expansion-with-work plant 36 which may be constituted by a two-stage turbine or a thermal separator of a known type, comprising a group of pipes closed at one end and in which the gas is subjected to expansion with work, the corresponding energy being released in the form of heat, or still by a reciprocating-motion expansion machine coupled for instance to a piston compressor.

The gaseous nitrogen expanded in the plant 36 is mixed with the gaseous nitrogen resulting from the second cold separator and then passes through the heat exchanger 30 where it cools the nitrogen passing through the coil 29 and is injected into the said nitrogen liquefaction circuit through the conduit 16 before the heat exchanger 17.

The distillation column 5, the re-boiler drum 6, the heat exchangers 17, 18, 30, the cold separators 31 and 32, the expansion-with-work plant 36 are placed in a chamber filled with low-temperature gaseous nitrogen, the said chamber being shown in FIG. 1 by the dotted outline 40.

The device just described operates as follows:

The liquefied-natural-gas vapours are conveyed from the tank 1 into the fractioning column 5 where they are cooled by contact with the liquid rich in nitrogen proceeding from the reflux drum 10. The nitrogen contained in the natural-gas vapours remains in a gaseous state, whereas the tower bottom liquid, which is constituted by a mixture rich in hydrocarbons and poor in nitrogen, is then returned to the re-boiler drum 6. The latter is at the boiling temperature of nitrogen-free liquid-natural-gas, so that the hydrocarbon mixture returned into the tank 1 contains practically no nitrogen.

The vapours from the top of the distillation column 5 are conveyed into the reflux drum 10 where they are partially liquefied. The distillate constituted by the remaining gaseous nitrogen is conveyed into the previously described nitrogen liquefaction circuit where it is first successively heated in the exchangers 17, 18 and 19 and then compressed in the compressor 20, cooled by passing through the coils of the exchangers 19, 20, 25, 18, 17, 30, and then either condensed in the cold separators 31 and 32 or expanded in the plant 36 and recycled into the liquefaction circuits.

In case of nitrogen overproduction, the gaseous nitrogen may be made to escape to open air through the conduit 41 placed right before the compressor. Use may also be made of the heat exchangers 22 and 25 to heat the liquefied natural gas contained in the tank 1 and intended for either the boiler of a tanker or a network for distribution to consumers.

In this case, the natural gas is delivered by a pump 42 into the coil 43 of a heat exchanger 44, and then into the coil 45 of a second heat exchanger 46, supplied, for instance, with high-temperature water from the heat exchanger 22. The natural gas thus vaporized may either pass through the heat exchanger 25 where it takes heat from the compressed nitrogen, or be used directly.

A portion of the natural gas vaporized at the outlet of the exchanger 46 is conveyed into the exchanger 44 to vaporize the liquid natural gas.

An alternative embodiment of the invention is shown in FIG. 2, wherein, instead of arranging on one and the same shaft-line the motor 21, the multi-stage compressor 20 and the multi-stage expansion plant 36, the same function may be fulfilled by grouping on three different shaft-lines an electric motor (or a steam turbine), a single-stage or two-stage compressor and a single-stage or two-stage expansion plant. In this case, it is preferable to select comparable pressure levels for the outlet of a compressor and the inlet of the corresponding turbine in each of the modules thus formed. This, indeed, enables the thrust on the shaft bearings of the modules to be reduced.

According to this modification of the invention, the compression and expansion circuit for the gaseous nitrogen, shown in FIG. 2, comprises three electric motors 51, 52, 53 which may also be replaced by steam turbines, three compressors 54, 55, 56 ensuring low-pressure, medium-pressure and high-pressure levels respectively. With each of these motor-compressor sets
are respectively associated turbines 57, 58, 59 for the expansion of the compressed nitrogen.

In this case, the gaseous nitrogen, after having passed through the exchangers 17, 18, 19, passed successively through the three compression stages 54, 55, 65 and is cooled after each compression in a heat exchanger 60 using for instance water or any other suitable refrigerating fluid, the circulation pumps and circuits of which are not shown. Thereafter, the nitrogen repasses, as in the first embodiment, through the heat exchangers 19, 18, the re-boiler drum 6 and the exchanger 17. The compressed nitrogen then passes through the coils of three exchangers 61, 62, 63 and then arrives in a first cold separator 64 wherefrom the gaseous nitrogen is conveyed to the turbine 59 and the liquid nitrogen is conveyed to a second cold separator 65. The gaseous nitrogen partially expanded in the turbine 59 passes through the cold separator 65 and then through the heat exchanger 63 and the second turbine 58. The liquid nitrogen proceeding from the cold separator is injected into a third separator 66 into which is also conveyed the expanded gaseous nitrogen proceeding from the turbine 58. The gaseous nitrogen contained in the separator 66 is again conveyed in an exchanger 62 and then passes in the turbine 57 where it is expanded and then conveyed into a fourth cold separator 67. Likewise, the liquid nitrogen from the separator 66 is returned into the separator 67. The gaseous nitrogen from the latter separator then passes through the heat exchanger 61 and is injected at the beginning of the nitrogen liquefaction cycle, before the exchanger 17.

FIG. 3 illustrates an example of embodiment of a motor-compressor-turbine set corresponding to one of the sets used in the embodiment shown in FIG. 2. In this case, the motor, for instance 51, is connected through a step-up gear 70 and bearings 71, 72, to the compressor 54 and the turbine 57. In the example illustrated, the compressor 54 is provided with a tangential outlet and an axial inlet.

On board ships, where an auxiliary boiler is generally available for the ship's steam requirements, it is preferable to form the motor-compressor-turbine sets by using a steam turbine instead of the motor, a centrifugal compressor and a centripetal expansion turbine as shown in FIG. 4. The steam turbine 80, the compressor 81 and the expansion turbine 82 are mounted in one and the same body. The latter, as well as the volutes and diffusers of the expansion turbine, are made from cryogenic metal. The various elements are assembled within the common body through the medium of heat-insulating members arranged to avoid any heat-conducting bridges between the said elements. Moreover, the pressure of the steam used in the turbine 81 is slightly lower than the nitrogen pressure in order to avoid any pollution of the nitrogen by the steam at the rotary joints.

The main advantage of the arrangement just described consists in the use of a modular construction system and in that the power used in each module is only a fraction of the total power, thus facilitating the supply of energy by the networks on board a ship. Moreover, it is possible to achieve various dimensions and rotational speeds in each of the modules.

The nitrogen cooling cycle according to the invention is illustrated in FIG. 5, where the entropy values $S$ are plotted in abscissae against enthalpy values $H$ plotted in ordinates.

At A, nitrogen is vaporized through condensation of the liquefied-natural-gas vapours in the distillation column 5. The line A B shows the heating of the gaseous nitrogen in the heat exchangers 17, 18, 19, whereas the line B C corresponds to the compression of the nitrogen in a four-stage compressor 20. The curve C D corresponds to the cooling of the nitrogen compressed in the exchangers 22, 19, 25, 18, 27, 17, 29 and the cold separators 31 and 32. The line D E corresponds to the expansion of the gaseous nitrogen in the plant 36, whereas the dotted line E A represents the vaporization of the liquid nitrogen and the compression of the vapour in the blower 3.

Owing to the method and device of the invention, the production of nitrogen on board a methane tanker is always much higher than the quantity of liquid nitrogen consumed by the ship, either to compensate for the refrigerant fluid losses in the natural-gas vapour liquefaction unit, or to pre-cool and to fill the tanks with an inert atmosphere. In the case of a methane tanker having just received a natural-gas cargo, the tank 1 is, of course, full of liquefied natural gas. So is the reservoir 2, the liquid nitrogen contained in the latter having been produced mainly during the empty return trip of the methane tanker. Since the tank 1 is practically full, the distillation column 5 operates at its full working rate since, the amount of methane to be re-liquefied being at a maximum. Part of the necessary cold may be obtained by slowly vaporizing the liquid nitrogen of reservoir 2. During the return trip, when the tanks 1 have been emptied, the volume of gas conveyed to the distillation tower is greatly reduced. Indeed, the boil-off in the liquefied-natural-gas tanks is reduced when the latter contain only a small amount of liquid. The refrigerating capacity necessary to re-liquefy the methane is therefore reduced and the plant may be used to condensate a larger fraction of the nitrogen contained in these evaporations. The liquid nitrogen thus produced accumulates in the reservoir 2 which progressively fills during the return trip, enabling the volume of nitrogen conveyed to the compressor therefore differs very little from that conveyed to the compressor during the outward trip, in the course of which the tanks 1 are practically full and the reservoir 2 empties. Thus, the time difference in phase of the variations of the levels in the liquefied-natural-gas tanks 1 and in the liquid nitrogen reservoir results in a regulation of the rate of flow from the compressor and from the expansion plant 36. The relatively regular use of these machines enables them to be better dimensioned.

In case the invention is applied to land storage tanks, the heat exchanger 25 enables the cold of the natural gas to be recovered and used to produce an additional amount of liquid nitrogen, which is stored in the reservoir 2. In the same manner as on board methane tankers, the volume of nitrogen sucked by the nitrogen compressor remains substantially constant in time.

Considering the case of a natural gas, the nitrogen content of which is not negligible, such as, for instance, Algerian natural gas, at least ten times the amount of nitrogen necessary for the ship's needs is available, in which case the excess nitrogen is rejected to the atmosphere after having given up all its sensible heat (from $-150^\circ$ to $+10^\circ$C approximately) to the nitrogen which is to be re-liquefied. This additional quantity of cold is far from being negligible and the refrigerating power to
be supplied for the re-liquefaction of the liquefied
natural-gas vapours is thus reduced by about 12 per-
cent.

In the case of land storage, the nitrogen produced in
excess is stored and then sold.

Of course, the invention is by no means limited to the
forms of embodiment described and illustrated, which
have been given by way of example only. In particular,
it comprises all the means constituting technical equiva-
15 lents to the means described as well as their combina-
tions, should the latter be carried out according to the
spirit of the invention.

What is claimed is:

1. A device for treatment of natural gas stored in liq-
uefied state, comprising: tank means containing said
liquefied natural gas and including a stop vapor space
filled with the gaseous phase consisting of the vapors
resulting from the boil-off of said liquefied-natural-gas;
fractional distilling column means comprising 9 bot-
tom collecting sump portion for holding reliquefied-
15 natural-gas, an overhead vapor space collecting top
portion for confining separated gaseous nitrogen and
intermediate upper and lower portions and a sump por-
tion; first vapor conveying duct means connecting said
top vapor space of said tank means to said intermediate
lower portion of said fractional distilling column
means; first vapor pump means inserted in said first
duct means and having its suction side communicating
with said top vapor space and its discharge side com-
municating with said fractional distilling column
means; reboiler vessel means including a lower liquid
phase holding portion for containing reboiling lique-
20 fied-natural-gas and an upper gaseous phase holding
portion for confining vapors of liquefied-natural-gas;
heat exchange pipe coil means contained within said
lower liquid phase holding portion; first liquid-
conveying duct means connecting said sump portion of
said fractional distilling column means to the inlet of
said lower liquid phase holding portion of said reboiler
vessel means; first liquid pump means inserted in said
second cut means and having its suction side communi-
cating with said sump portion of said fractional distillat-
ing column means and its discharge side in communica-
tion in communication with said lower liquid phase
holding portion of said reboiler vessel means; second
liquid-conveying duct means connecting the outlet of
said lower liquid phase holding portion of said reboiler
vessel means with said top vapor space of said tank
means; second vapor-conveying duct means connect-
ing said upper gaseous phase holding portion of said re-
boiler vessel means to said intermediate lower portion
of said fractional distilling column means; container
means containing liquid-nitrogen and including a top
vapor space filled with the gaseous phase released by
the boil-off of said liquid-nitrogen; reflux condenser
drum means immersed in said liquid-nitrogen within
said container means and including a condensate hold-
ing portion containing liquid-nitrogen and a vapor
holding portion filled with gaseous nitrogen; third liq-
uid-conveying duct means connecting said condensate
holding portion of said reflux condenser drum means to
said intermediate upper portion of said fractional distil-
lating column means; second liquid pump means in-
serted in said third liquid-conveying duct means and
having its suction side communicating with said con-
densate holding portion of said reflux condenser drum
means and its discharge side communicating with said
intermediate upper portion of said fractional distillat-
ing column means; third vapor-conveying duct means
connecting said overhead collecting top portion of said
fractional distilling column means to the inlet of an
immersed portion of said vapor holding portion of said
reflux condenser drum means; main gaseous flow heat
exchanger means having a refrigerating medium flow
lath and a heating medium flow path respectively inter-
connected in series, said treating medium flow path in-
cluding pipe coil means interconnected in series within
said heating medium flow path of said main heat ex-
changer means; fourth vapor-conveying duct means
connecting the outlet of said top vapor space of said
container means to the inlet of said refrigerating me-
dium flow path of said main gaseous flow heat ex-
changer means; second gas pump means inserted in
said fourth vapor-conveying duct means and having its
suction side communicating with said top vapor space
of said container and its discharge side communicating
with said refrigerating medium flow path of said main
gaseous flow heat exchanger means; power driven com-
pressor means with at least one compression stage hav-
ing an inlet and an outlet connected to the refrigerating
medium flow path and to the heating medium flow
path, respectively, of said main heat exchanger means;
and cold phase separator means including a condensate
holding portion for containing liquid-nitrogen and a
vapor holding portion for confining non-condensed
gaseous nitrogen; fourth liquid-conveying duct means
connected said condensate holding portion of said
cold phase separator means into the body of liquid ni-
trogen contained in said container; an outlet and an
inlet of said vapor holding portion of said cold phase
separator being connected to the inlet of the refrigerat-
ing medium flow path and to the outlet of the heating
medium flow path, respectively, of said main heat ex-
changer means.

2. A method of progressively cryogenically purifying
a stored stationary body of liquefied-natural-gas con-
taining at least a major portion of methane and a sub-
stantial amount of nitrogen mixed therewith by contin-
uous cyclic process comprising the steps of: providing
a stored stationary body of liquid nitrogen; collecting
the boil-off forming the gaseous phase built up on the
5 15 20 25 30 35 40 45 50 55
60
65
top of said body of liquefied-natural-gas; effecting a
fractional distillation of said boil-off through heat ex-
change with a boiling refrigerant by using a cold reflux
liquid previously separated and reliquefied-nitrogen
whereby the nitrogen contained in said boil-off is sepa-
rated as a gas therefrom and the so purified remaining
boil-off is reliquefied; collecting the purified hydrocar-
bon-enriched reliquefied natural gas resulting as the
bottoms from said fractional distillation and returning
it to said body of liquefied-natural-gas which is thus
also gradually enriched; collecting the separated over-
head gaseous nitrogen and the gaseous nitrogen result-
ing from evaporation of said reflux liquid and convey-
ging same in a confined condition into said body of liq-
id-nitrogen in heat exchanging relationship therewith
so as to condense at least a part of said gaseous nitro-
gen, the nitrogen condensate serving as said reflux liq-
uid; recovering the cold gaseous nitrogen evaporated
from said body of liquid-nitrogen and that resulting
from said nitrogen distillate, reliquefying said recov-
ered gaseous nitrogen and feeding the reliquefield-
nitrogen back to said body of liquid-nitrogen, reboiling
at least one portion of said collected reliquefied-
natural-gas at the boiling temperature of a nitrogen-free liquid-natural-gas through heat exchange with hot gaseous nitrogen derived from the nitrogen reliquefaction cycle and feeding the vapors of liquefied-natural-gas resulting from said reboiling step to said fractional distillation step to supply reboiling heat thereto, said hot gaseous nitrogen being cooled thereby, while the reboiled substantially nitrogen-free liquid-natural-gas is returned to said body of liquefied-natural-gas; whereas said reliquefying of said recovered gaseous nitrogen comprises the steps of: reheat said cold recovered gaseous nitrogen through heat exchange with hot compressed gaseous nitrogen which is cooled thereby; compressing said heated gaseous nitrogen in at least one stage and after cooling same at least through said heat exchange with said cold recovered gaseous nitrogen and with said reboiling purified liquid-natural-gas; subjecting said cooled compressed gaseous nitrogen to at least one first cold phase separation for condensing at least a part of said gaseous nitrogen; collecting and returning said condensed liquid-nitrogen to said body of liquid-nitrogen; said method also comprising the steps of: collecting the cold compressed gaseous nitrogen which has not been condensed during said cold phase separation; expanding at least one portion thereof in at least one stage while recovering work produced by said expansion and using said work as power for assisting the compression step; preheating at least one portion of said expanded gaseous nitrogen through heat exchange with that compressed gaseous nitrogen which is about to undergo said cold phase separation thereby further cooling said last-named compressed gaseous nitrogen; and mixing said preheated compressed gaseous nitrogen with the steam of said recovered gaseous nitrogen arriving from said body of liquid-nitrogen before further preheating same; expanding another portion of said non-condensed gaseous nitrogen and recovering the work produced thereby as power for assisting the compression step; and mixing said expanded portion with said one portion before preheating the same.

3. A method of progressively cryogenically purifying a stored stationary body of liquefied natural gas containing at least a major portion of methane and a substantial amount of nitrogen mixed therewith by a continuous cyclic process comprising the steps of: providing a stored stationary body of liquid-nitrogen; collecting the boil-off from the gaseous phase built up at the top of said body of liquefied-natural-gas; effecting a fractional distillation of said boil-off through heat exchange with a boiling refrigerant by using a cold reflux liquid previously separated and reliquefied nitrogen whereby the nitrogen contained in said boil-off is separated as a gas therefrom and the purified remaining boil-off is reliquefied; collecting the purified hydrocarbon-enriched reliquefied natural gas resulting as the bottoms from said fractional distillation and returning it to said body of liquefied-natural-gas which is thus also gradually enriched; collecting the separated overhead gaseous nitrogen and the gaseous nitrogen resulting from evaporation of said reflux liquid and conveying same in a confined condition into said body of liquid-nitrogen in heat exchanging relationship therewith so as to condense at least a part of said gaseous nitrogen, the nitrogen condensate serving as said reflux liquid; recovering the cold gaseous nitrogen evaporated from said body of liquid-nitrogen and that resulting from said nitrogen distillate; reliquefying said recovered gaseous nitrogen and feeding the reliquefied gaseous nitrogen back to said body of liquid-nitrogen, reboiling at least one portion of said collected reliquefied-natural-gas at the boiling temperature of a nitrogen-free liquid natural gas through heat exchange with hot gaseous nitrogen derived from the nitrogen reliquefaction cycle and feeding the vapors of liquefied-natural-gas resulting from said reboiling step to said fractional distillation step to supply reboiling heat thereto, said hot gaseous nitrogen being cooled thereby, while the reboiled substantially nitrogen-free liquid-natural-gas is returned to said body of liquefied natural gas; whereas said reliquefying of said recovered gaseous nitrogen comprises the steps of: reheat said cold recovered gaseous nitrogen through heat exchange with hot compressed gaseous nitrogen which is cooled thereby; compressing said heated gaseous nitrogen in at least one stage and aftercooling same at least through said heat exchange with said cold recovered gaseous nitrogen and with said reboiling purified liquid-natural-gas; subjecting said cooled compressed gaseous nitrogen to at least one first cold phase separation for condensing at least a part of said gaseous nitrogen; collecting and returning said condensed liquid-nitrogen to said body of liquid nitrogen; and said method comprising further the steps of collecting the cold compressed gaseous nitrogen which has not been condensed during said cold phase separation; preheating at least one portion thereof through heat exchange with that compressed gaseous nitrogen which is about to undergo said cold phase separation thereby further cooling said last-named compressed gaseous nitrogen; and mixing said preheated compressed gaseous nitrogen with the steam of said recovered gaseous nitrogen arriving from said body of liquid-nitrogen before further preheating same; expanding another portion of said non-condensed gaseous nitrogen and recovering the work produced thereby as power for assisting the compression step; and mixing said expanded portion with said one portion before preheating the same.

4. A device according to claim 3, comprising aftercooling means inserted in series between the outlet of each stage of said compressor means and the inlet of the heating medium flow path of said main heat exchanger means and extraneous coolant circulating means, said aftercooler means being cooled by the circulation of extraneous coolant of said extraneous coolant circulating means.

5. A device according to claim 3, comprising work-producing gas expansion means having its inlet connected to another outlet of the vapor holding portion of said cold phase separator means and its outlet connected to an inlet of the refrigerating medium flow path of said main heat exchanger means.

6. A device according to claim 5, wherein said work-producing gas expansion means comprises a tubular thermal separator.

7. A device according to claim 5, wherein said work-producing gas expansion means comprising at least one reciprocating piston engine coupled to at least one piston compressor forming compressor means and motor means, said compressor means also being operatively connected to motor means.

8. A device according to claim 7 wherein said work-producing gas expansion means comprises turbine means having at least one stage, compressor means which comprise multiple stages, interstage cooler means separating said multiple stages and extraneous coolant means for said stages said turbine means and said compression means being directly coupled and operatively connected to said motor means.
9. A device according to claim 1, wherein said main heat exchanger means comprise first and second heat exchangers whose said pipe coil means are interconnected.

10. A device according to claim 5, comprising further gas flow heat exchanger means having a heating medium flow path connected in series between the outlet of the heating medium flow path of said main heat exchanger means and said inlet of the vapor holding portion of said cold phase separator means and a refrigerating medium flow path connected in series between said inlet of the refrigerating medium flow path of said main heat exchanger means and on the other hand said one outlet of the vapor holding portion of said cold phase separator means and said outlet of said work-producing gas expansion means.

11. A device according to claim 10, wherein said cold phase separator means consist of first and second cold phase separators, the outlet of the condensate holding portion of said first cold phase separator being connected to the inlet of the vapor holding portion of said second cold phase separator whereas the outlet of the heating medium flow path of said further heat exchanger means is connected to an inlet of the vapor holding portion of said first cold phase separator and the outlet of said first cold phase separator is connected to the inlet of said work-producing gas expansion means, the outlet of the vapor holding portion of said second cold phase separator being connected to the inlet of the refrigerating medium flow path of said further heat exchanger means.

12. A device according to claim 11, including a conduit connecting the outlet of the refrigerating medium flow path of said main exchanger means to the inlet of said outlet of the medium flow path of said work-producing means and controllable vent pipe means branched off said conduit.

13. A device according to claim 11, including third liquid pump means at least the suction side of which is immersed in the liquefied-natural-gas contained in said tank means; pipe line means leading from the discharge side of said third liquid pump means to the outside of said tank means towards a consumer station and auxiliary heat exchanger means comprising a heating medium flow path connected to the coolant outlet of said aftercooling means and a refrigerating medium flow path inserted in series into said pipe line means upstream of said auxiliary heat exchanger means.

14. A device according to claim 13, including additional heat exchanger means comprising a heating medium flow path having an inlet connected through branch duct means to said pipe line means downstream of said auxiliary heat exchanger means and an outlet connected to the top vapor space of said tank means, and a refrigerating medium flow path inserted in series into said pipe line means upstream of said auxiliary heat exchanger means.

15. A device according to claim 11, wherein said power driven compressor means comprise a plurality of separate, respectively low intermediate and high pressure turbine-motor-compressor sets having each one a working gas expansion turbine, a motor and a compressor, and drive shaft means, said drive shaft means operatively and mechanically coupling each set, the gas flow path of said compressors being interconnected in series and inserted between the outlet of the refrigerating medium flow path entering the low pressure compressor and the inlet of the heating medium flow path fed by the final high pressure compressor to said main heat exchanger means, with interstage extra-neous gas coolant supplied cooler means connected in series between any two successive compressors and gas aftercooler means cooled by said extraneous coolant connected in series between the outlet of said high pressure compressor and the inlet of the heating medium flow path of said main heat exchange means; said cold phase separator means comprising a primary cold phase separator whose vapor holding portion is connected through an outlet to the inlet of the turbine of the final high pressure turbine-motor-compressor set and a like plurality of secondary cold phase separators associated with said plurality of turbine-motor-compressor sets, respectively; a like plurality of further gas flow heat exchangers also associated with said turbine-motor-compressor sets, respectively, the heating medium flow paths of which are interconnected in series and inserted between the outlet of the heating medium flow path of said main heat exchanger means and an inlet of the vapor holding portion of said primary cold phase separator; the condensate holding portion of said primary cold phase separator being connected to an inlet of the vapor holding portion of the first secondary cold phase separator; the vapor holding portion of each secondary cold phase separator being connected through an outlet to an inlet of the refrigerating medium path of the associated further heat exchanger, the outlet of which is connected to the inlet of the turbine of the next successive turbine-motor-compressor set, except for the corresponding outlet of the further heat exchanger associated with the first or low pressure turbine-motor-compressor set which outlet is connected to the inlet of the refrigerating medium flow path of said main heat exchanger means; the condensate holding portion of each secondary cold phase separator being connected through an outlet to an inlet of the vapor holding portion of the next secondary cold phase separator, except for the outlet of the last secondary cold phase separator associated with the first or low pressure turbine-motor-compressor set which outlet is connected to said fourth liquid-conveying duct means.

16. A device according to claim 15, wherein each turbine-motor-compressor set comprises multiplying gear means with two output shafts operatively coupled to drive shafts of said turbine and said compressor, respectively, and with an input shaft operatively coupled to said motor, said compressor having an axially directed gas inlet and a tangentially directed gas outlet.

17. A device according to claim 15, mounted on board a ship and wherein the turbine-motor and compressor of each turbine-motor-compressor set are housed in a same casing and said motor comprises a steam turbine whose steam pressure is slightly lower than the gas pressure in said gas flow path.

18. A method according to claim 3, wherein said cold phase separation comprises a first separation producing liquid nitrogen which is subject to a second separation producing liquid nitrogen which is returned to said body of liquid nitrogen whereas the non-condensed gaseous nitrogen resulting from said first separation is expanded and mixed with the non-condensed gaseous nitrogen resulting from said second separation.
UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

PATENT NO.: 3,857,251
DATED: December 31, 1974
INVENTOR(S): Jean Alleaume

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 7, line 16, "stop" should read --top--; column 7, line 21, "space" should be deleted; column 7, line 41, "cut" should read --duct--; column 7, line 44, "in communciation" should be deleted; column 7, line 64, "liquid" should read --liquid--; column 8, line 8, "lath" should read --path--; column 8, line 8, delete "respectively" and substitute --and--; column 8, line 21 "dirven" should read --driven--; column 10, line 57, after "forming" insert --said--; same line delete 
and" and substitute --; said device further comprising--; same line before "motor" insert --said--; column 10, line 62, insert --whereas said-- before "compressor"; column 10, line 63, delete "which"; column 10, line 65, delete "stages" and substitute --interstage cooler means--; column 10, line 66, change "compression" to --compressor--; column 12, line 1, delete "to" and substitute --, said refrigerating medium flow path and said heating medium flow path being those of--; column 12, line 3 delete "gas" preceding "coolant"; same line after "supplied" insert --gas--; column 12, line 5, after "coolant" insert --and--.

Signed and Sealed this
Third Day of August 1976

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks
UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,857,251 Dated December 31, 1974

Inventor(s) Jean Alleaume

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 60, "supplies previously the frigories"
should read -- previously supplies the amount of cold --.

Column 5, line 4, "passed" should read -- passes --; line 47,
before "volutes" insert -- stationary --. Column 7, line 64,
"liquid" should read -- liquid --. Column 8, line 21,
"dirven" should read -- driven --.

Signed and sealed this 8th day of April 1975.

(SEAL)
Attest:
RUTH C. MAJON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents
and Trademarks