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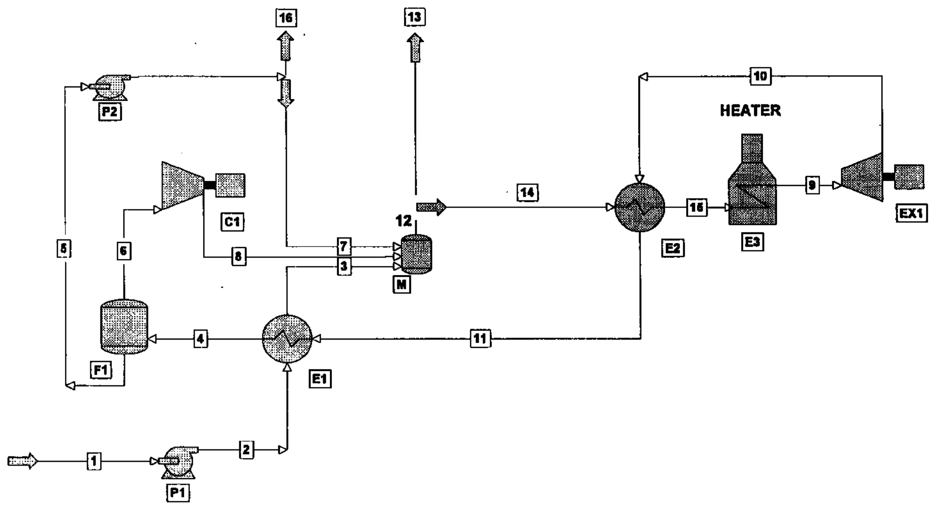
(71) Applicant: **ENIRICERCHE S.p.A.**
20097 S. Donato Milanese (Milano) (IT)

(72) Inventor: **Soave, Giorgio**
S. Donato Mil.se (Milano) (IT)

(74) Representative: **Gennari, Marco**
Eniricerche S.p.A.,
BREL,
Via F. Maritano, 26
20097 San Donato Milanese (MI) (IT)

(54) Process for regasifying liquified natural gas

(57) Process for regasifying LNG (liquified natural gas) by means of an open thermodynamic cycle using as operating fluid part of the same regasified LNG, which allows the cold produced in the regasification itself to be used to generate mechanical energy.



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Description

The present invention relates to a process for regasifying LNG (liquified natural gas) which allows the cold produced in the regasification itself to be used to generate mechanical energy.

LNG is stored at atmospheric pressure and at its boiling point (about -160°C). To regasify it and send it for distribution it is energetically convenient to pump it first at gasduct pressure (70 bars) and regasify it at this pressure.

The regasification can be obtained in two ways:

- by heat exchange with combustion fumes, in equipment called "submersed flame" in which the heat is supplied by combustion of part (about 2%) of the same gas produced;
- by heat exchange with sea water, which is returned colder.

The first solution, although relatively economical with respect to the plant cost, is rather expensive in the operating costs.

The second, on the other hand, has low operating costs and is therefore generally preferred for large regasification plants, but requires strong investments for the heat exchangers (low ΔT) and above all for the removal, treatment and discharge operations of the sea water which, to avoid thermal short circuits, must be removed and discharged in points which are distant from each other. In addition it creates problems of an environmental nature (to the extent that the regulations in force have fixed a maximum ΔT of the water).

The cold coming from the regasification of LNG could therefore be exploited in various ways instead of being dispersed in the sea or in combustion fumes.

The regasification plant, for example, could be coupled with a conventional thermal plant, using the heat discharged from this and thus allowing an improved efficiency of the thermodynamic cycle, as the condensation of the discharge vapor of the turbines could be carried out at lower temperatures than the normal ones of 40-50°C.

The solution described is not very effective, using the cold (air) available at temperatures of between -160 and 0°C, for the condensation of vapor at temperature above zero. It is possible however to conceive particular thermodynamic cycles which fully exploit the characteristics of the cold source for producing larger quantities of energy with higher yields. In this way the advantage of the elimination of the sea water would be combined with that of the production of high efficiency electric energy.

Patent application IT-26948 A74 claims a regasification plant using a closed nitrogen cycle which allows a good yield (from 58 to 60%) and a good power production (28-29 MW per $10^9 Nm^3/a$, which however has problems linked to the infiltration of natural gas into the nitrogen.

We have found that by using a thermodynamic cycle integrated with the regasification, it is possible to obtain yields and power equivalent to those obtained with the process described in the above patent, and at the same time considerably reducing the problems arising from its use.

The process for regasifying LNG, of the present invention, is carried out by means of an open thermodynamic cycle using as operating fluid part of the regasified LNG itself, which allows the cold produced in the regasification to be exploited to generate mechanical energy.

The open thermodynamic cycle preferably comprises the following steps:

- preheating, heating with an external heat source and subsequent expansion of the operating fluid under pressure, with the production of mechanical energy;
- cooling of the expanded operating fluid by thermal exchange in countercurrent with the operating fluid to be preheated;
- further cooling by thermal exchange with the LNG causing its regasification;
- compression of the cooled operating fluid and subsequent mixing with the regasified LNG;
- removal of part of the stream under pressure obtained from the mixing to be used as operating fluid in the thermodynamic cycle.

When after the cooling of the expanded operating fluid by thermal exchange with the LNG, a liquid phase is formed, it is necessary to have, after said thermal exchange, a separation step of the liquid phase from the gaseous phase of the operating fluid.

In this case the liquid phase, after being pumped, is also sent, at least in part, to the step in which the mixing of the LNG regasified with the compressed gas takes place or is removed, at least in part, to separate and/or recover the heavier components.

The liquid phase, before being mixed with the regassified GNL and with the compressed gas, can be preheated in order to exploit the cold and diminish the irreversibilities linked to the mixing of streams at very different temperatures, or it can be gradually injected into the vapor from which is was previously separated, along the compression path, to lower its temperature and reduce the compression operation.

The mixing of the regasified LNG and expanded gas must take place at the same pressure: the compression of the expanded cooled gas must therefore produce a pressure which is equal to that of the LNG regasified after the thermal exchange with the operating fluid.

In addition it is preferable for the operating conditions to be such as to have two streams to be mixed at the same temperature.

For a greater thermodynamic yield it is preferable for the heating to take place with an external heating source having a temperature higher than 600°C, which can consist of, for example, combustion fumes.

The heating of the operating fluid can be carried out in one or more steps: when several steps are used, gas turbine discharges can also be adopted.

The enclosed figure provides a better illustration of the invention and represents a pratical embodiment which however does not limit the scope of the invention itself.

The LNG (1) is pumped (in P1) at a pressure of 70 bars, and is then heated (in E1) to room temperature with the heat obtained from the gaseous operating fluid (11) of the open thermodynamic cycle.

The LNG obtained from the regasification (3) is mixed in the mixer (M) with the gaseous operating fluid under pressure (8) and with the possible liquid operating fluid (7).

The gaseous mixture obtained (12) is divided between the product (13) and the gas (14) which must effect the cycle as operating fluid.

The gas (14) is preheated in the exchanger (E2) in countercurrent with the same gas leaving (10) the expansion turbine (EX1), then the preheated stream (15) is heated with an external heating source (E3) at the highest possible temperature, and the stream obtained (9) is then expanded in the turbine (EX1) at a suitable intermediate pressure.

The expanded stream (10) is cooled, first in the exchanger (E2) in countercurrent with the same gas under pressure (14), and then, completing the cooling, in the exchanger (E1) with the LNG (2).

The cooled stream (4), if it contains a liquid phase, is separated in the separator (F1) into a liquid phase (5) and a gas phase (6), which is compressed in the compressor (C1) at a pressure of 70 bars and sent (8) to the mixer (M).

The liquid phase (5), after being pumped (in P2) at a pressure of 70 bars can be sent (7), at least in part, to the mixer (M), where it vaporizes, or it can be removed (16) to obtain liquid products lightening the gas produced.

The following examples provide a better illustration of the present invention.

<u>Examples 1-2</u>

Two types of gases were taken into consideration, a compound from pure methane (example 1), the other relatively rich (example 2), these two gases are representative of all actual situations.

The process scheme is analogous to that represented in the enclosed figure without separating and/or recovering however the possible liquid phase 7 (i.e. the stream 16 is not present).

General calculation data adopted:

- final heating temperature of the gas in the oven: 700°C
- adiabatic yield of the expansion turbine: 80%
- adiabatic yield of the gas compressor: 85%
- minimum ΔT in the exchangers: 10°C
- reference regasification potential: 10^9 Nm^3/year out of 8000 hours/year.

For each type of gas different expansion pressures were adopted to try and find for each pressure the optimum conditions in point 4 (which are shown in tables I and II below) so as to obtain in the mixing of streams (7) and (8) a gaseous fluid at the same temperature as stream (3).

From the calculations it appeared that the maximum power productions and maximum yields are obtained when the cooling temperature in point 4 is minimum, in line with the necessity of having a higher ΔT at the set value (10° in our case) in the heat exchanges.

The optimum operating conditions involve a partial condensation of the gas in the maximum cooling point, less for methane, greater for the rich gas which has a much higher dew point.

TABLE 1

Example 1- Pure methane (1.54913 kmoles/s = $10^9 Nm^3/a$)
(1): LNG : boiling point = -161.6°C; P = 1 bar
(P1): Pumping at P = 70 bars; N_1 = 475.8 kW
(2): T = -158.2°C; P = 1 bar
(9): T = 700°C; 3.3900 kmoles
(EX1): Expansion at P = 6 bars; N_2 = 47052 kW
(10): T = 491.8°C; P = 6 bars;
(4): T = -134.5°C; P = 6 bars;vaporized fraction=0.991 molar
(5): 0.0305 kmoles
(P2): Pumping at P = 70 bars; N_3 = 9.88 kW
(7): T = -129.5°C; P = 70 bars;
(6): 3.3595 kmoles
(C1): Compression at P = 70 bars; N_3 = 14654 kW
(8): 30.75°C; P = 70 bars
(3): 28.44°C
(14): 3.39 kmoles
(11): T = 38.44°C (ΔT = 10°C)
(15): T = 468.5°C
ΣN = 31912 kW
Heat (12) - (9): 51933 kW
Total yield: 61.5%

TABLE 2

Example 2- 83/10/5/2% $C_1/C_2/C_3/C_4$ (1.54913 kmoles/s = $10^9 Nm^3/a$)
(1): boiling point = -159.7°C; P = 1 bar 1.54913 kmoles/s = $10^9 Nm^3/a$
(P1): Pumping at P = 70 bars; N_1 = 508.2 kW
(2): T = -156.7°C; P = 1 bar
(9): T = 700°C; 3.3635 kmoles
(EX1): Expansion at P = 8 bars; N_2 = 42927 kW
(10): T = 541.3°C; P = 8 bars;
(4): T=-80.9°C; P=8 bars;vaporized fraction=0.880 molar
(5): 0.4036 kmoles
(P2): Pumping at P = 70 bars; N_3 = 188.2 kW
(7): T = -77.9°C; P = 70 bars;
(6): 2.9599 kmoles
(C1): Compression at P = 70 bars; N_3 = 15196 kW
(8): 81.9°C; P = 70 bars
(3): 29.65°C
(14): 3.3635 kmoles
(11): T = 39.65°C (ΔT = 10°C)
(15): T = 514.9°C
ΣN = 27035 kW
Heat (12) - (9): 49821 kW
Total yield: 54.3%

Claims

1. A process for regasifying LNG (liquified natural gas) by means of an open thermodynamic cycle, which allows the cold produced in the regasification itself to be exploited to generate electric energy, characterized in that it uses as operating fluid part of the regasified LNG.

2. The process according to claim 1 wherein the operating fluid consisting of part of the same gasified natural gas is used in the thermodynamic cycle comprising the following steps:

   - preheating, heating with an external heat source and subsequent expansion of the operating fluid under pressure, with the production of mechanical energy;
   - cooling of the expanded operating fluid by thermal exchange in countercurrent with the operating fluid to be preheated;
   - further cooling by thermal exchange with the LNG causing its regasification;
   - compression of the cooled operating fluid and subsequent mixing with the regasified LNG;
   - removal of part of the stream under pressure obtained from the mixing to be used as operating fluid in the thermodynamic cycle.

3. The process according to claim 2 wherein, when, following the cooling of the operating fluid expanded by thermal exchange with the LNG, a liquid phase is formed, after said thermal exchange there is a separation step of the liquid phase from the gaseous phase of the operating fluid.

4. The process according to claim 3, wherein the liquid phase is pumped and also sent, at least in part, to the step

where the mixing of the regasified LNG with the compressed gas takes place.

5. The process according to claim 3 wherein the liquid phase is pumped and removed, at least in part, to recover and/or separate the heavier components.

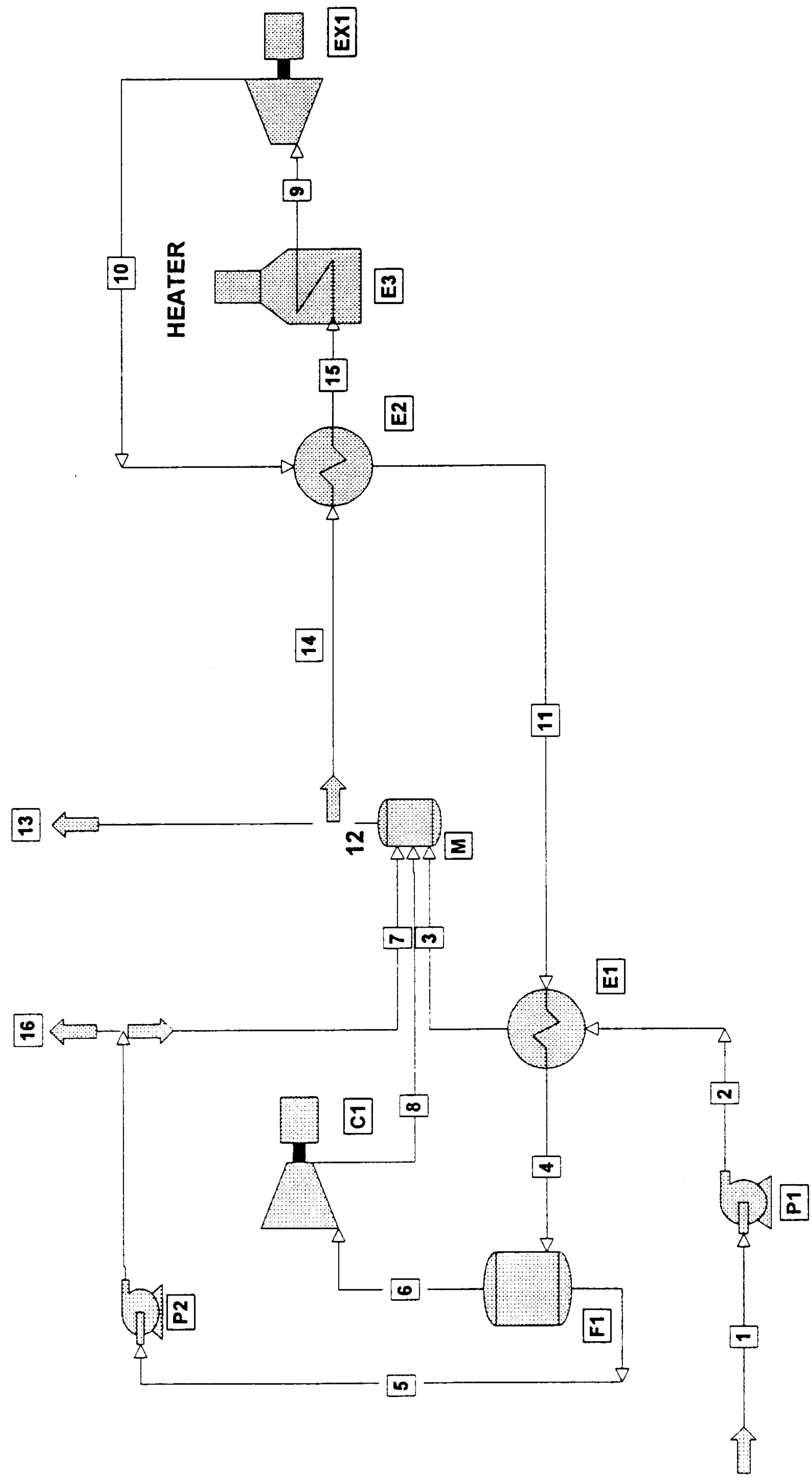
6. The process according to claim 4 wherein the liquid phase, before being mixed with the regasified LNG and with the compressed gas, is preheated.

7. The process according to claim 3 wherein the liquid phase is pumped and gradually injected, at least in part, into the vapor, from which is was previously separated, along the compression path thereof.

8. The process according to claim 2 wherein the external heat source of the heating of the operating fluid consists of combustion fumes.

9. The process according to claim 2 wherein the heating of the operating fluid takes place in various steps.

10. The process according to claim 9 wherein the gas turbine discharges are used as a further heating step of the operating fluid.


EX1
9
10
HEATER
E3
15
E2
14
11
13
12
M
7
3
E1
16
8
C1
2
4
P1
6
F1
P2
5
1