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(54) **Convenrsion of liquefied natural gas**

(57) A method of and apparatus for converting liquefied natural gas (LNG) to a superheated fluid through vaporisation and superheating of the LNG employs a first main heat exchanger 10 in a series with a second main heat exchanger 12. The first main heat exchanger is heated by a condensing first heat exchange fluid (propane) flowing in a first heat exchange circuit 20 including a first supplementary heat exchanger 14 for revaporising the first heat exchange fluid and the second main heat exchanger 12 by a condensing second heat exchange fluid flowing in a second heat exchange circuit 22 including a second heat exchanger 16 for vaporising the second heat exchange fluid.

The circuits 20 and 22 may share a common vessel for collecting condensate. The condensing pressure of the heat exchange fluid in the first circuit 20 is less than condensing pressure of the heat exchange fluid in the second circuit 22. The flow of the heat exchange fluids through the first main heat exchanger 10 and the second main heat exchanger 12 is controlled by valves 32 and 36.

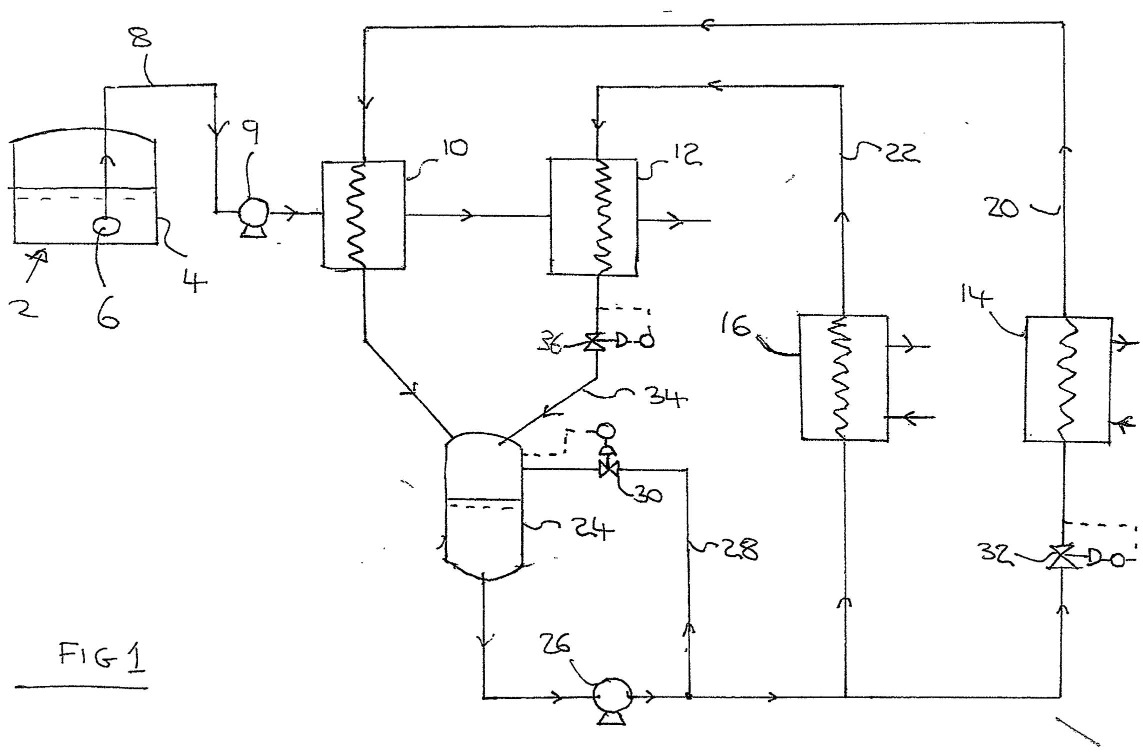

FIG 1

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Description

[0001] The present invention relates to a method and apparatus for converting liquefied natural gas to a superheated fluid. The method and apparatus are particularly suited for use on board a ship or other ocean-going vessel, for example, an FSRU (Floating Storage and Regasification Unit).

[0002] Natural gas is conveniently stored and transported in liquid state. It is generally used, however, in gaseous state. There is therefore a need to convert large volumes of liquefied natural gas to a superheated fluid, typically a gas below the critical pressure of natural gas, but sometimes a fluid at a pressure above the critical pressure.

[0003] US Patent 6 945 049 discloses a method and apparatus for vaporising liquefied natural gas. Liquefied natural gas is pumped through a first heat exchanger to effect vaporisation and a second heat exchanger to raise the temperature of the vapour to approximately ambient temperature, or a little below ambient temperature. The first heat exchanger is heated by a heat exchange fluid, such as propane, flowing in a closed cycle. The propane changes from gaseous to liquid state in the first heat exchanger and is converted to a gas again in a plurality of heat exchangers which are typically heated by a flow of sea water. In the second heat exchanger, the vaporiser natural gas is heated by a flow of steam.

[0004] The method and apparatus according to the invention aim at reducing the surface area of corresponding heat exchangers without undue loss of thermodynamic efficiency.

[0005] According to the present invention there is provided a method of converting liquefied natural gas to a superheated fluid, comprising the steps of:

a. passing a flow of the natural gas under pressure through a first main heat exchanger and a second main heat exchanger in series with one another;
b. heating the flow of the natural gas in the first main heat exchanger by heat exchange with a first heat exchange fluid flowing in a first endless circuit at a first pressure, the first heat exchange fluid undergoing a change of state from vapour to liquid in said first main heat exchanger;
c. further heating the flow of the natural gas in the second main heat exchanger by heat exchange with a second heat exchange fluid flowing in a second endless circuit at a second pressure, the second heat exchange fluid being of the same composition as the first heat exchange fluid and undergoing a change of state from vapour to liquid in said second main heat exchanger;
d. collecting liquid first heat exchange fluid from the first main heat exchanger and liquid second heat exchange fluid from the second main heat exchanger;
e. re-vaporising in the first endless heat exchange fluid circuit a flow of the liquefied first heat exchange fluid in a first supplementary heat exchanger and supplying the resulting vapour as the first heat exchange fluid to the first main heat exchanger;
f. re-vaporising a flow of the second liquid heat exchange fluid in a second supplementary heat exchanger in the second endless heat exchange circuit and supplying the resulting vapour as the second heat exchange fluid to the second main heat exchanger; and wherein
g. the condensing pressure of the first heat exchange fluid in the first main heat exchanger is less than the condensing pressure of the second heat exchange fluid in the second main heat exchanger.

[0006] In some preferred examples, the said resulting vapour in step (e) may be turbo-expanded intermediate the first supplementary heat exchanger and the first main heat exchanger. The turbo-expansion makes possible power recovery from the vapour.

[0007] The invention also provides apparatus for converting liquefied natural gas to a superheated fluid comprising:

a. a first main heat exchanger and a second main heat exchanger in series with one another arranged for the heating of the liquefied natural gas in heat exchange with a condensing first heat exchange fluid and a condensing second heat exchange fluid, respectively;
b. a first endless lower condensing pressure heat exchange fluid circuit extending through the first main heat exchanger;
c. a second endless higher condensing pressure heat exchange fluid circuit extending through the second main heat exchanger, wherein
d. the first and second endless heat exchange fluid circuits both include a liquid collection vessel for collecting condensed heat exchange fluid;
e. the first endless heat exchange fluid circuit extends through a first supplementary heat exchanger for re-vaporising condensed first heat exchange fluid;
f. the second endless heat exchange fluid circuit extends through a second supplementary heat exchanger for re-vaporising condensed second heat exchange fluid; and
g. the apparatus also comprises means for controlling the flow rate of the first heat exchange fluid through the first main heat exchanger and the flow rate of the second heat exchange fluid through the second main heat exchanger.

[0008] The apparatus according to the invention may also include in the first endless heat exchange fluid circuit a turbo-expander intermediate the first supplementary heat exchanger and the first main heat exchanger. The turbo-expander may be operatively associated with power generation means, thereby making possible the recovery of power.

[0009] The employment of different condensing pressures in the first and second heat exchange fluid circuits makes it possible to keep down the surface area of the first and second main heat exchangers without undue loss of thermodynamic efficiency. Preferably, the temperature difference between the temperature of the first heat exchange fluid at its inlet to the first main heat exchanger and the temperature of the natural gas at its exit from the first main heat exchanger is greater than the temperature difference between the temperature of the second heat exchange fluid at its inlet to the second main heat exchanger and the temperature of the natural gas at its exit from the second main heat exchanger.

[0010] In the method and apparatus according to the invention each of the main and supplementary heat exchangers may comprise a single body or core or a plurality of bodies or cores. If plural, the heat exchange bodies or cores may be arranged in series or in parallel.

[0011] The apparatus according to the invention preferably additionally comprises at least one liquid pump for taking liquid heat exchange fluid from the collection vessel and for circulating it through the first and second endless heat exchange circuits.

[0012] The liquid heat exchange fluid in the first and second heat exchange circuits is preferably collected in a common collection vessel which is shared by the first and second heat exchange fluid circuits. Accordingly, the first heat exchange fluid is preferably the same as the second heat exchange fluid.

[0013] Alternatively, each circuit may have its own collection vessel and its own liquid pump. In this case, the first heat exchange fluid may be different from the second heat exchange fluid.

[0014] The flow rates of the first and second heat exchange fluids through the first and second main heat exchangers, respectively, are preferably varied in accordance with any changes in the thermal load thereupon. Accordingly, the control means preferably includes a first valve means adapted to be operated so as to vary the flow rate of the first heat exchange fluid through the first main heat exchanger in accordance with any variation in the thermal load thereupon. Likewise, the control means preferably includes a second valve means which is also preferably adapted to be operated so as to vary the flow rate of the second heat exchange fluid through the second main heat exchanger in accordance with any variations in the thermal load thereupon. If the first endless heat exchange circuit includes a turbo-expander, the flow rate may be controlled by the inlet guide vanes of the turbo-expander.

[0015] In examples of the method and apparatus according to the invention in which the first endless heat exchanger circuit includes a turbo-expander, this circuit preferably additionally includes a liquid pump with a variable frequency drive operable to vary the pressure ratio across the turbo-expander. This enables the circuit to cater for different re-vaporising and condensing temperatures.

[0016] The first valve means is preferably positioned in the first endless heat exchange fluid circuit intermediate the liquid pump and the inlet of the first heat exchange fluid to the first supplementary heat exchanger. The second valve means is preferably positioned in the second endless heat exchange fluid circuit immediate the outlet for the second heat exchange fluid from the second main heat exchanger and the common collection vessel.

[0017] The apparatus according to the invention preferably also includes a conduit for recirculating condensed heat exchange fluid to the common collection vessel and a third valve means in the conduit for opening (or increasing the flow rate through) the said conduit in the event of the thermal load on the apparatus falling below a chosen minimum.

[0018] Preferably the pressure in the ullage space of the common collection vessel is essentially the condensing pressure of the first endless circuit exchange fluid.

[0019] The first and second liquid heat exchange fluids may be heated in the first and second supplementary heat exchangers by any convenient medium, but the temperature of this medium influences the choice of the heat exchange fluid. Sea water is typically a convenient medium to use on board a seagoing vessel, but other media such as fresh water, engine cooling water or a mixture of water and ethylene glycol can be used instead. In general, if the said medium is supplied at approximately ambient temperature, propane is a preferred choice for both the first and second heat exchange fluids. Propane is readily available commercially and has thermodynamic properties that enable the condensing temperatures in the first and second main heat exchangers to be selected to be above minus 40°C but below plus 15°C. Other heat exchange fluid can be used instead of or in a mixture with propane. Such alternative or additional heat exchange fluids contain ethane, butane, other hydrocarbons and fluorocarbon refrigerants, particularly R134(a). The selected heat exchange fluid preferably has a positive equilibrium pressure down to minus 30°C or minus 40°C. If the temperature of the seawater (or alternative medium) is particularly low, the first and second heat exchange fluids may both be composed of the same mixture of propane and ethane. If, on the other hand, such temperature is particularly high, the first and second heat exchange fluids may both be composed of the same mixture of propane and butane.

[0020] The first and second heat exchange fluids may be fully vaporised and, if desired, superheated in the first and second supplementary heat exchangers. If desired, there may be a superheating section separate from the vaporising section. Both such sections may be provided in different bodies. Alternatively, they may be partially vaporised in the first and second heat exchangers, in which case both the first and second heat exchange circuits may include a phase separator to disengage unvaporised heat exchange fluid from its vapour. The resulting liquid may be returned to the collection vessel associated with the heat exchange circuit.

[0021] The method and apparatus according to the invention will now be described by way of example with reference to the accompanying drawings, in which:

Figures 1 to 4 are general schematic flow diagrams of different forms of LNG vaporisation apparatus;

Referring to Figure 1, an LNG facility 2 typically comprises at least one thermally-insulated storage tank 4 having a submerged LNG pump 6. The outlet of the pump 6 communicates with a conduit 8 having disposed therealong, outside the facility 2, a second LNG pump 9. The outlet of the pump 9 communicates with an apparatus according to the invention for heating the flow of LNG. The facility is typically located aboard a seagoing vessel, which may, for example, be a so-called FSRU (Floating Storage and Regasification Unit). There is from time-to-time a need to deliver natural gas from the facility 2 at elevated pressure and a non-cryogenic temperature, typically a temperature close to ambient temperature. The apparatus as shown in Figure 1 enables the natural gas to be delivered at a chosen pressure, rate and temperature. This apparatus includes a first main heat exchanger 10, a second main heat exchanger 12, a first supplementary heat exchanger 14 and a second supplementary heat exchanger 16. The first and second main heat exchangers 10 and 12 are both adapted to be heated by a common condensing heat exchange fluid flowing countercurrently to the natural gas.

[0022] There is a first endless heat exchange fluid circuit 20 that causes the heat exchange fluid to flow through the first main heat exchanger 10 and the first supplementary heat exchanger 14, and a second such circuit 22 which causes the heat exchange fluid to flow through the second main heat exchanger 12 and the second supplementary heat exchanger 16. The circuits 20 and 22 have in common a liquid heat exchange fluid collection vessel 24 and a pump 26 for raising the pressure to which the liquid heat exchange fluid is subjected. It is, however, possible for each circuit to have its own dedicated collection vessel. The first endless heat exchange fluid circuit 20 extends from a liquid outlet from the first main heat exchanger 10 to the liquid collection vessel 24 and includes the pump 26. Downstream of the pump 26 the first heat exchange fluid circuit 20 extends through the first supplementary heat exchanger 14 in which the liquid heat exchange fluid is reconverted to a vapour. The heat exchange fluid circuit 20 is completed by a conduit placing the outlet for vaporised heat exchange fluid from the first supplementary heat exchanger 14 in communication with an inlet for vaporised heat exchange fluid to the main heat exchanger 10. If desired, both the heat exchange circuits may communicate or be able to be placed in communication with a source of back up heat exchange fluid to enable any loss of heat exchange fluid from the circuits to be made up.

[0023] Sufficient flow of the heat exchange fluid through the first main heat exchanger 10 is provided so as to vaporise all the liquefied natural gas flowing there through and to superheat it to a chosen temperature. It is to be appreciated, however, that the pump 8 may typically raise the pressure of the liquefied natural gas to above its critical pressure, say to about 100 bar, in which case, the natural gas enters the first main heat exchanger 10 is a supercritical fluid, so strictly speaking, is not vaporised. Whether or not the liquefied natural gas is presented to the first main heat exchanger 10 as a supercritical fluid, the apparatus shown in Figure 1 is operated so as to ensure that the temperature at which it leaves the first main heat exchanger 10 is in a chosen temperature range, somewhat below 0°C.

[0024] The second heat exchange circuit 22 is operated so as to raise the temperature of the natural gas further to a chosen delivery value. In the second heat exchange fluid circuit 22, some liquid heat exchange fluid is diverted from the first heat exchange fluid circuit 20 from a region downstream of the pump 26 and flows through the second supplementary heat exchanger 16 in which it is vaporised. The resulting vapour flows to an inlet for heat exchange fluid to the second main heat exchanger 12. This heat exchange fluid is condensed in the second main heat exchanger 12 by heat exchange with the natural gas, the natural gas thereby being heated to the desired temperature. The so condensed heat exchange fluid passes from the second main heat exchanger to the common collection vessel 24 via a pipe or conduit 34.

[0025] The necessary heat for the first and second supplementary heat exchangers 14 and 16 may be provided by any convenient supplementary heat exchange medium.

[0026] The liquid vessel 24 is provided with a recycle conduit 28. One end of the conduit 28 terminates in a common region of the heat exchange circuits 20 and 22 which is downstream of the outlet of the pump 26 but upstream of where the second heat exchange circuit 22 branches from the first heat exchange circuit 20. The other end of the conduit 28 terminates within the liquid collection vessel 24. A valve 30 is disposed within the conduit 28. The valve 30, when open, enables condensed heat exchange fluid to be withdrawn from the heat exchange circuits 20 and 22. Such withdrawal may be carried out if the thermal load on the main heat exchangers 10 and 12 falls below a chosen level.

[0027] The rate of flow of heat exchange fluid through the main heat exchangers 10 and 12 are controlled by a first valve 32 and a second valve 36, respectively. The first valve 32 is positioned intermediate the outlet of the pump 26 and the inlet for the heat exchange fluid to the first supplementary heat exchanger 14. The second valve 36 is positioned in the conduit 34. The valves 32 and 36 are operated so as to vary the flow rates of the heat exchange fluid through the first and second main heat exchangers 10 and 12, respectively with any changes in the thermal load thereupon.

[0028] In operation, the heat exchange fluid effects indirect heat exchange between the supplementary heat exchange medium and the liquefied natural gas. On board a ship or FSRU, seawater is a particularly convenient supplementary heat exchange medium. It can, for example, be taken from the surroundings of the ship or FSRU. Other media such as fresh water, engine cooling water, or a mixture of water and ethylene glycerol can be used instead. The supplementary heat exchange medium may flow in open or closed circuit. If in closed circuit, the temperature of the supplementary heat exchange medium may be readily controlled by means of an additional heat source, for example, a boiler, and the heat exchange fluid selected in accordance with this temperature. The preferred heat exchange fluid is propane. Propane is readily available commercially and has thermodynamic properties that enable the condensing temperatures in the first and second main heat exchangers 10 and 12 to be above minus 40°C but below +15°C. If the supplementary heat exchange medium, for example, sea water, flows in open circuit, however, its temperature may vary throughout the year and with the geographical location of the ship or FSRU. The incoming temperature of the sea water may accordingly vary between, say, 10 and 27°C. If desired, the propane may be mixed with ethane for lower supplementary heat exchange medium temperatures and with butane for higher temperatures. In general, the choice of the heat exchange fluid needs to be made in light of these factors, bearing in mind that the heat exchange fluid desirably has a positive equilibrium pressure down to minus 30°C and preferably down to minus 40°C.

[0029] In typical operation, the thermal load on the heat exchangers 10 and 12, that is the heat they are required to provide in order to raise the temperature of the LNG from its storage temperature of below minus 150°C to a chosen supply temperature (for example +5°C) is likely to vary. The apparatus shown in Figure 1 is able to meet these variations. The flow of the heat exchange fluid through the first supplementary heat exchanger 14 is typically such as to cool the sea water or other medium by 5 to 7°C. The heat exchange fluid is changed in state from liquid to vapour in the first supplementary heat exchanger 14 and may be slightly superheated. It is this vapour that serves to heat the LNG in the first main heat exchanger 10. The heat exchange fluid condenses again in the first main heat exchanger 10. The operation of the second main heat exchanger 12 is analogous to that of the first main heat exchanger 10.

The natural gas is heated in it by indirect heat exchange with condensing heat exchange fluid. The operation of the valves 32 and 36 has the effect of making the condensing pressure in the second main heat exchanger 12 higher than in the first main heat exchanger 10. The difference in the condensing pressures is equal to the differential pressure across the pump 26 minus the pressure drops in the relevant piping and heat exchangers. Further, the condensing pressure in the first main heat exchanger is equal to the condensing pressure in the ullage space of the common collection vessel. This pressure is not fixed but tends to float as the heat exchange circuits adjust to a change in the thermal load. For higher loads, the condensing pressure in the first main heat exchanger 10 is lower, these pressure changes being brought about by adjustment of the valve 32 in response to changes in the thermal load upon the heat exchanger 10. If desired, the adjustment of the valve 32 may be effected automatically in response to a parameter which is a function of the changes in thermal load. The valve 36 may be similarly adjusted and because the condensing pressure in the first main heat exchanger 10 floats, so does the condensing pressure in the second main heat exchanger 12.

[0030] Because the condensing pressure in the second main heat exchanger 12 is greater than the condensing pressure in the first main heat exchanger 10, the sizes of the two heat exchangers can readily be kept down without undue loss of thermodynamic efficiency even at low sea water (or other supplementary exchange medium) temperatures. In general, the first main heat exchanger 10 is called upon to meet a larger thermal load than the second main heat exchanger. It is preferred that the difference in temperature between the heat exchange fluid entering the first main heat exchanger 10 and the natural gas exiting it is greater than the difference in temperature between the heat exchange fluid entering the second main heat exchanger 12 and the natural gas exiting from it.

[0031] It can be understood that the pressure difference across the pump 26 is a significant factor in determining the difference in condensing pressure and hence condensing temperature between the two main heat exchangers 10 and 12. Typically, the pump 26 has a constant frequency drive and therefore the differential pressure cannot be altered. This is not a disadvantage as the apparatus shown in Figure 1 can generally cope with normal changes in thermal load that are encountered. If the thermal load falls too much causing the control valves 32 and 36 to throttle the flow too much, the setting of the valve 30 is able automatically to maintain the minimum flow through the pump 26 necessary for it be run. If the thermal load rises too much, then a valve (not shown) in the LNG pipeline can be adjusted to reduce the LNG flow. At lower sea water inlet temperatures however (say in the order of 10°C), it may be advantageous to use a variable frequency pump 26 and operate it at a slightly increased pressure differential to reduce the condensing temperature in the first main heat exchanger 10 at higher thermal loads.

[0032] In a typical example, the first main heat exchanger 10 raises the temperature of the LNG to minus 40 to minus 20°C so that it vaporises (unless at a supercritical pressure) and the second main heat exchanger 12 further raises its temperature to 0 to 5°C. The first main heat exchanger 10 may typically meet 80% of the thermal load and the second main heat exchanger 12 the remaining 20%. In this example, the heat exchange fluid is propane, and the supplementary heat exchange medium is seawater.

[0033] The apparatus shown in Figure 1 is essentially self-adjusting to changes in the LNG vaporisation load placed upon it. If the LNG flow decreases, there will be a lower rate of condensation of propane in the heat exchangers 10 and 12 and the propane pressure will increase in the supplementary heat exchangers 14 and 16 and the common collection vessel. This increase in pressure has a compensatory effect on the propane vaporisation rate by decreasing the temperature difference between the supplementary heat exchange medium and the vaporising propane in the heat exchangers 14 and 16. The heat exchange circuits 20 or 22 are able to adjust to keep the temperature of the vaporised propane no more than a few degrees Celsius above its boiling temperature. Similarly, if the LNG flow increases, there will be a higher rate of condensation of propane in the heat exchangers 10 and 12 and the propane pressure will fall in the supplementary heat exchangers 14 and 16 and the common collection vessel 24. This decrease in pressure has a compensatory effect on the propane vaporisation rate by increasing the temperature difference between the supplementary heat exchange medium and the vaporising propane in the heat exchangers 14 and 16. The heat exchange circuits 20 and 22 are able to adjust to keep the temperature of the vaporised propane no more than a few degrees Celsius above its boiling temperature.

[0034] The apparatus shown in Figure 2 enables superheating of the propane (or other heat exchange fluid in the supplementary heat exchangers 14 and 16 to be avoided. Now the heat exchange circuits 20 and 22 both include phase separators, and the supplementary heat exchangers 14 and 16 effect only partial vaporisation of the propane or other heat exchange fluid.

[0035] A first phase separator 40 is provided in the first heat exchange circuit 20 intermediate the propane exit and of the first supplementary heat exchanged 14 and the propane inlet end of the first main heat exchanger 10. If desired, as shown in Figure 2, the first supplementary heat exchanger 14 may be split and comprise two parallel heat exchange units 14(a) and 14(b).

[0036] The first phase separator 40 has an inlet 42 for a liquid-vapour propane mixture to a vessel 44, in which the liquid phase collects.

[0037] The phase separator vessel 44 has a first outlet 46 at its top for vapour communicating with the propane inlet to the first main heat exchanger 10, and a second outlet 48 at its bottom for liquid propane communicating with the common collection vessel 24. A flow control valve 52 is located at the conduit 50 and is operatively associated with a level detector 54 in the vessel 44 such that a constant liquid propane level can be maintained thereon. A demister 56 is located in the vessel 44 in order to disengage droplets of liquid from the vapour flowing to the first main heat exchanger 10.

[0038] A second phase separator 60 is provided in the second heat exchange circuit 22 intermediate the propane exit end of the second supplementary heat exchanger 16 and the propane exit end of the second main heat exchanger 12. The second phase separator 60 has an inlet 62 for a liquid-vapour mixture to a vessel 64, a first outlet 66 at its top for vapour communicating with the propane inlet to the second main heat exchanger 12, and a second outlet 68 at its bottom for liquid propane communicating via conduit 70 with the common liquid propane collection vessel 24. A flow control valve 72 is located in the conduit 70 and is operatively associated with a level detector 74 in the vessel 64 such that a constant liquid level can be maintained therein. A demister 76 is located in the vessel 64 in order to disengage droplets of liquid from the vapour flowing to the second main heat exchanger 12.

[0039] The heat exchanger 14 may be split into two parallel parts.

[0040] In view of the provision of the phase separators 40 and 60, the recycle conduit 28 and the valve 30 are omitted from the apparatus shown in Figure 2. Operation of the apparatus shown in Figure 2 is analogous to that shown in Figure 1, but there is no superheating of the propane in the heat exchangers 14 and 16.

[0041] In comparison with the apparatus shown in Figure 1, the apparatus shown in Figure 2 has an additional liquid pump 80 to assist in the circulation of the liquid propane. The pumps 26 and 80 are operable to vary, if desired, the pressure difference between the propane in the heat exchange circuits 20 and 22. In operation, the heat exchange circuits 20 and 22 are self-adjusting in a manner analogous to the corresponding circuits in the apparatus shown in Figure 1. The apparatus may be charged with propane via a conduit 78 having stop valve 79 disposed therein and terminating in the collection vessel 24.

[0042] Referring now to Figure 3 of the drawings, there is shown a variation on the apparatus shown in Figure 2, in which instead of there being a common collection vessel 24, both the heat exchange circuits 20 and 22 have dedicated liquid propane collection vessels 82 and 84, respectively. Thus the circuits 20 and 22 are separate from each other and each circuit has its own liquid propane supply pipeline 86, having a stop valve 88 disposed therein, terminating in the vessel 82, and the circuit 22 has a liquid propane supply pipeline 90, with a stop valve 92 disposed therein, terminating in the vessel 64.

[0043] In operation of the apparatus shown in Figure 3, the pumps 26 and 80 simply create the necessary circulation of liquid propane and compensate for pressure drops in the apparatus. In other respects, operation of the apparatus shown in Figure 3 is analogous to that shown in Figure 2.

[0044] Referring now to Figure 4 of the drawings, there is shown a variant of the apparatus shown in Figure 1 in which instead of there being a common collection vessel 24, both the heat exchange circuits 20 and 22 have dedicated liquid collection vessels 82 and 84, respectively. Thus the circuits 20 and 22 have dedicated liquid collection vessels 82 and 84, respectively. Thus the circuits 20 and 22 are separate from each other. The circuit 20 has its own liquid heat exchange fluid supply pipeline 86, having a stop valve 88 disposed therein, terminating in the vessel 82, and the circuit 22 has a liquid heat exchange fluid supply pipeline 90, with a stop valve 92 disposed therein, terminating the vessel 84. The heat exchange fluid in the circuit 20 can be of the same or a different composition from that of the heat exchange fluid in the circuit 22.

[0045] The circuit 20 has a turbo-expander 100 intermediate the heat exchange vapour exit from the supplementary heat exchanger 14 and the heat exchanger vapour inlet to the main heat exchanger 10. The turbo-expander 100 is operatively associated in a conventional way with a generator 104 that is connected to an electrical grid 106, thus making possible power recovery from the heat exchanger fluid. The cycle pump 26 is designed correspondingly for a higher differential pressure to suit the turbine design pressure ratio and is equipped with a variable frequency drive 110 to adapt the pressure ratio for different re-vaporising and condensing temperatures.

[0046] In operation of the apparatus shown in Figure 4, the pump 26 creates the necessary pressure differential for the operation of the turbo-expander 100 to generate electrical power in addition to circulating the heat exchange fluid in the circuit 20. The pump 80 circulates the heat exchange fluid in the circuit 22. In addition, both pumps 26 and 80 compensate for pressure drops in the apparatus. In other respects, operation of the apparatus shown in Figure 4 is analogous to that shown in Figures 1 and 3.

Claims

1. According to the present invention there is provided a method of converting liquefied natural gas to a superheated fluid, comprising the steps of:

    a. passing a flow of the natural gas under pressure through a first main heat exchanger and a second main heat exchanger in series with one another;
    b. heating the flow of the natural gas in the first main heat exchanger by heat exchange with a first heat exchange fluid flowing in a first endless circuit at a first pressure, the first heat exchange fluid undergoing a change of state from vapour to liquid in said first main heat exchanger;
    c. further heating the flow of the natural gas in the second main heat exchanger by heat exchange with a second heat exchange fluid flowing in a second endless circuit at a second pressure, the second heat exchange fluid being of the same composition as the first heat exchange fluid and undergoing a change of state from vapour to liquid in said second main heat exchanger;
    d. collecting liquid first heat exchange fluid from the first main heat main heat exchanger and liquid second heat exchange fluid from the second main heat exchanger;
    e. re-vaporising in the first endless heat exchange fluid circuit a flow of the liquefied first heat exchange fluid in a first supplementary heat exchanger and supplying the resulting vapour as the first heat exchange fluid to the first main heat exchanger;
    f. re-vaporising a flow of the second liquid heat exchange fluid in a second supplementary heat exchanger in the second endless heat exchange circuit and supplying the resulting vapour as the second heat exchange fluid to the second main heat exchanger; and wherein
    g. the condensing pressure of the first heat exchange fluid in the first main heat exchanger is less than the condensing pressure of the second heat exchange fluid in the second main heat exchanger.

2. A method according to claim 1, wherein the liquid heat exchange fluid from the first and second heat exchangers is collected in a common collection vessel.

3. A method according to claim 2, wherein the pressure in the ullage space of the common collection vessel is essentially the condensing pressure of the first heat exchange fluid.

4. A method according to any one of the preceding claims, wherein the flow rate of the first heat exchange fluid through the first main heat exchanger is varied in accordance with any changes in the thermal load thereupon.

5. A method according to any of the preceding claims, wherein the temperature difference between the inlet temperature of the first heat exchange fluid at its inlet to the first main heat exchanger and the temperature of the natural gas at its exit from the first main heat exchanger is greater than the temperature difference between the temperature of the second heat exchange fluid at its inlet to the second main heat exchanger and the temperature of the natural gas at its exit from the second main heat exchanger.

6. A method according to any one of the preceding claims, wherein the first and second heat exchange fluids are fully vaporised in the first and second supplementary heat exchangers, respectively.

7. A method according to claim 6, wherein the first and second heat exchange fluids are superheated in the first and second supplementary heat exchangers, respectively.

8. A method according to claim 6, wherein the first and second heat exchange fluids are superheated downstream of the supplementary heat exchangers.

9. A method according to any one of claims 1 to 5, wherein the first and second heat exchange fluids are partially vaporised in the first and second supplementary heat exchangers, respectively.

10. A method according to claim 9, additionally including the step of disengaging unvaporised heat exchange fluid from the vaporised heat exchange fluid.

11. A method according to any one of the preceding claims, wherein the first and second heat exchange fluids both comprise propane.

12. A method according to any of the preceding claims, where in the liquid heat exchange fluid is heated in the first and second supplementary heat exchangers by sea water.

13. A method according to claim 1 or any of claims 4 to 12 when not dependent from claim 2 or claim 3, wherein the first heat exchanger fluid has a different composition from that of the second heat exchange fluid.

14. A method according to claim 12, wherein the seawater flows in a closed circuit.

15. A method according to claim 14, wherein the seawater flows in an open circuit.

16. A method according to claim 1, or any one of claims 4 to 12 when not dependent from claim 2 or claim 3, wherein the said resulting vapour in step (e) is turboexpanded intermediate the first supplementary heat exchanger and the main heat exchanger.

17. Apparatus for converting liquefied natural gas to a superheated fluid, comprising:

a. a first main heat exchanger and a second main heat exchanger in series with one another arranged for the heating of the liquefied natural gas in heat exchange with a condensing first heat exchange fluid and a condensing second heat exchange fluid, respectively;
b. a first endless lower condensing pressure heat exchange fluid circuit extending through the first main heat exchanger;
c. a second endless higher condensing pressure heat exchange fluid circuit extending through the second main heat exchanger, wherein
d. the first and second endless heat exchange fluid circuits both include a liquid collection vessel for collecting condensed heat exchange fluid;
e. the first endless heat exchange fluid circuit extends through a first supplementary heat exchanger for re-vaporising condensed first heat exchange fluid;
f. the second endless heat exchange fluid circuit extends through a second supplementary heat exchanger for re-vaporising condensed second heat exchange fluid; and
g. the apparatus also comprises means for controlling the flow rate of the first heat exchange fluid through the first main heat exchanger and the flow rate of the second heat exchange fluid through the second main heat exchanger.

18. Apparatus according to claim 17, wherein the first and second endless heat exchange circuits have a common liquid collection vessel.

19. Apparatus according to claim 18, additionally including a liquid pump for taking a heat exchange fluid from the common collection vessel and for circulating it through the first and second endless heat exchange fluid circuits.

20. Apparatus according to claim 18 or claim 19, wherein said control means includes a first valve means which is adapted to be operated so as to vary the flow rate of the first heat exchange fluid through the first main heat exchanger in accordance with any variations in the thermal load thereupon.

21. Apparatus according to claim 20, when dependent from claim 19, wherein the first valve means has a position in the first endless heat exchange fluid circuit intermediate the said pump and the inlet of the first heat exchange fluid to the first supplementary heat exchanger.

22. Apparatus according to any of claims 17 to 21, wherein the control means includes a second valve means for controlling the flow rate through the second valve means for controlling the flow rate through the second main heat exchanger.

23. Apparatus according to Claim 21, wherein the second valve means is adapted to be operated so as to vary the flow rate of the second heat exchange fluid through the second main heat exchanger in accordance with variations in the thermal load on the second main heat exchanger.

24. Apparatus according to claim 22 or claim 23, when dependent from claim 18, wherein the second valve means has a position in the second endless heat exchange circuit intermediate the outlet for the second heat exchange fluid from the second main heat exchanger and the common collection vessel.

25. Apparatus according to any one of claims 19 to 24 , when dependent from claim 18, including a conduit for recirculating condensed heat exchange fluid to the common collection vessel, and a third valve means in the conduit for opening or increasing the flow rate in the said conduit in the event of the thermal load on the apparatus falling below a chosen minimum.

26. Apparatus according to claim 17 or claim 18, wherein both the first and second endless heat exchange circuits include a phase separator for disengaging unvaporised heat exchange fluid from vaporised heat exchange fluid.

27. Apparatus according to claim 17, wherein the first endless heat exchange circuit is independent of the second endless heat exchange circuit and includes a turbo-expander intermediate the first supplementary heat exchanger and the first main heat exchanger.

28. Apparatus according to claim 27, wherein the turbo-expander includes controllable guide vanes operable to control the flow of vapour in the first endless heat exchange circuit.

29. Apparatus according to claim 27 or claim 28, wherein the turbo-expander is operatively associated with power generation means.

30. Apparatus according to any one of the claims 27 to 29, wherein the first endless heat exchange circuit includes a pump with a variable frequency drive operable to vary the pressure ratio across the turbo-expander.

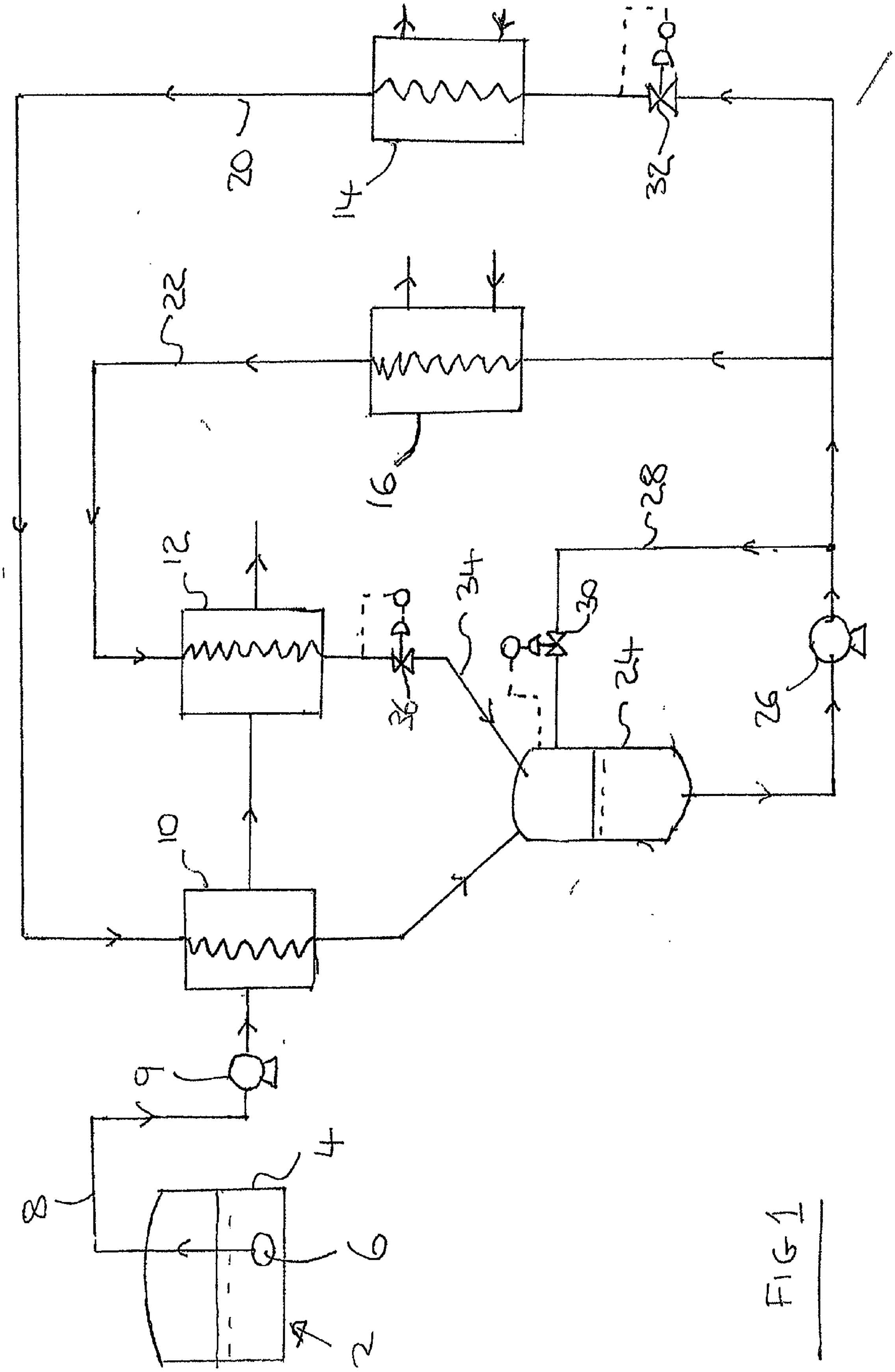

FIG 1

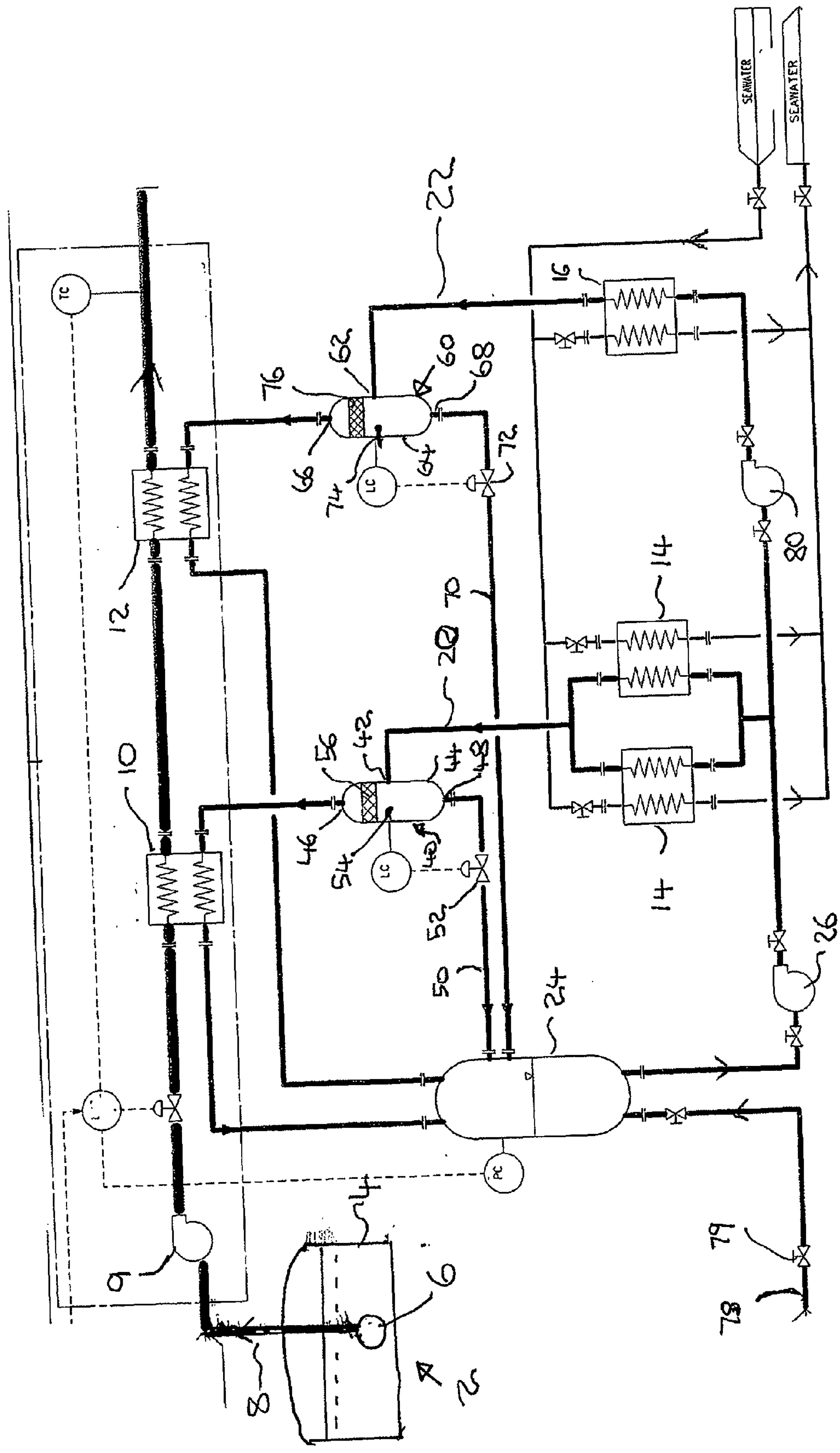
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FIG 2

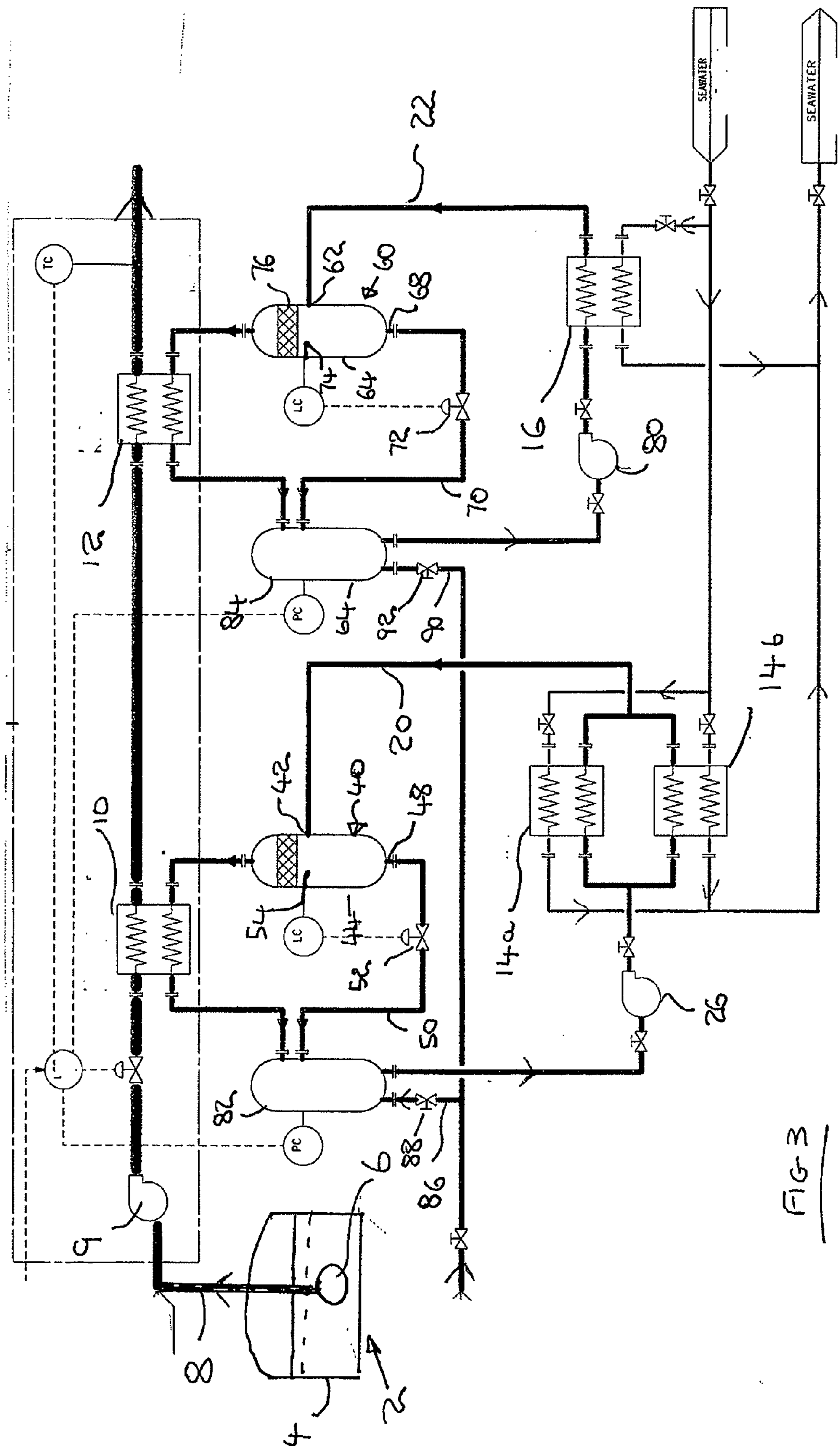

FIG 3

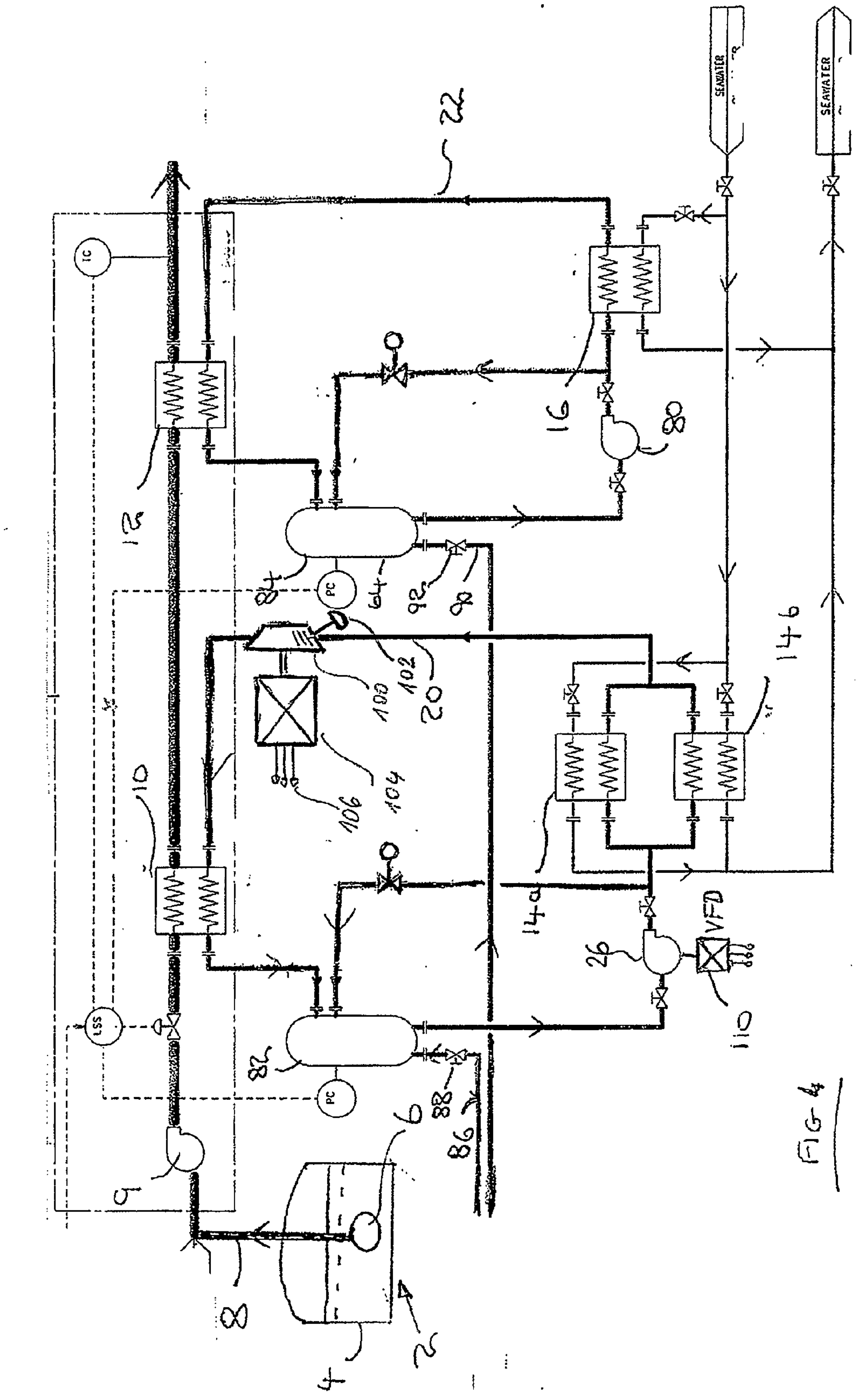

FIG 4

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EUROPEAN SEARCH REPORT

Application Number
EP 08 35 2024

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
Y	GB 2 008 239 A (BORSIG GMBH) 31 May 1979 (1979-05-31) * the whole document * -----	1-8, 16-24	INV. F17C9/02 F17C7/04
Y	DE 26 33 713 A1 (LINDE AG) 2 February 1978 (1978-02-02) * the whole document * -----	1-8, 16-24	
Y	KOCH, HEISS, STÄNGL: "Uebungsaufgaben + Musterlösungen" 1985, LEHRSTUHL A FÜR THERMODYNAMIK DER TUM , MÜNCHEN , XP002526658 * page 36 - page 40 * * pages 85-1 - page 87 * -----	1-8, 16-24	
Y	DE 19 22 779 A1 (LINDE AG) 25 June 1970 (1970-06-25) * the whole document * -----	1-8, 16-24	
A	EP 0 043 212 A (PETROCARBON DEV LTD [GB]) 6 January 1982 (1982-01-06) * page 9, paragraph 2 - page 12, paragraph 3 * -----	1-30	TECHNICAL FIELDS SEARCHED (IPC) F17C
A	US 2003/159800 A1 (NIERENBERG ALAN B [US]) 28 August 2003 (2003-08-28) * paragraph [0018] - paragraph [0041] * -----	1-30	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	7 May 2009	Stängl, Gerhard

CATEGORY OF CITED DOCUMENTS

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07-05-2009

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
GB 2008239 A	31-05-1979	BE 870807 A1	15-01-1979
		DE 2751642 A1	09-08-1979
		ES 474041 A1	16-04-1979
		FR 2409450 A1	15-06-1979
		IT 1101417 B	28-09-1985
DE 2633713 A1	02-02-1978	NONE	
DE 1922779 A1	25-06-1970	AT 289731 B	10-05-1971
EP 0043212 A	06-01-1982	DE 3172221 D1	17-10-1985
		JP 57046007 A	16-03-1982
		US 4400947 A	30-08-1983
US 2003159800 A1	28-08-2003	AU 2002242275 A1	09-09-2003
		CA 2477446 A1	04-09-2003
		CN 1623063 A	01-06-2005
		EP 1478875 A1	24-11-2004
		JP 2005519239 T	30-06-2005
		KR 20060042859 A	15-05-2006
		MX PA04008283 A	26-07-2005
		TW 568863 B	01-01-2004
		WO 03072993 A1	04-09-2003
		US 2008148742 A1	26-06-2008

EPO FORM P0459

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Patent documents cited in the description

- US 6945049 B **[0003]**