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(54) Conversion 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 propane and the second main heat exchanger 12 by a condensing second heat exchange fluid (also propane) flowing in a second heat exchange circuit 22 including a second heat exchanger 16 for vaporising the propane. The circuits 20 and 22 share a common vessel for collecting condensate. The condensing pressure of the propane in the first circuit 20 less than condensing pressure of the propane in the second circuit 22. The flow of the propane through the first main heat exchanger 10 and the second main heat exchanger 12 is controlled by valves 32 and 36.

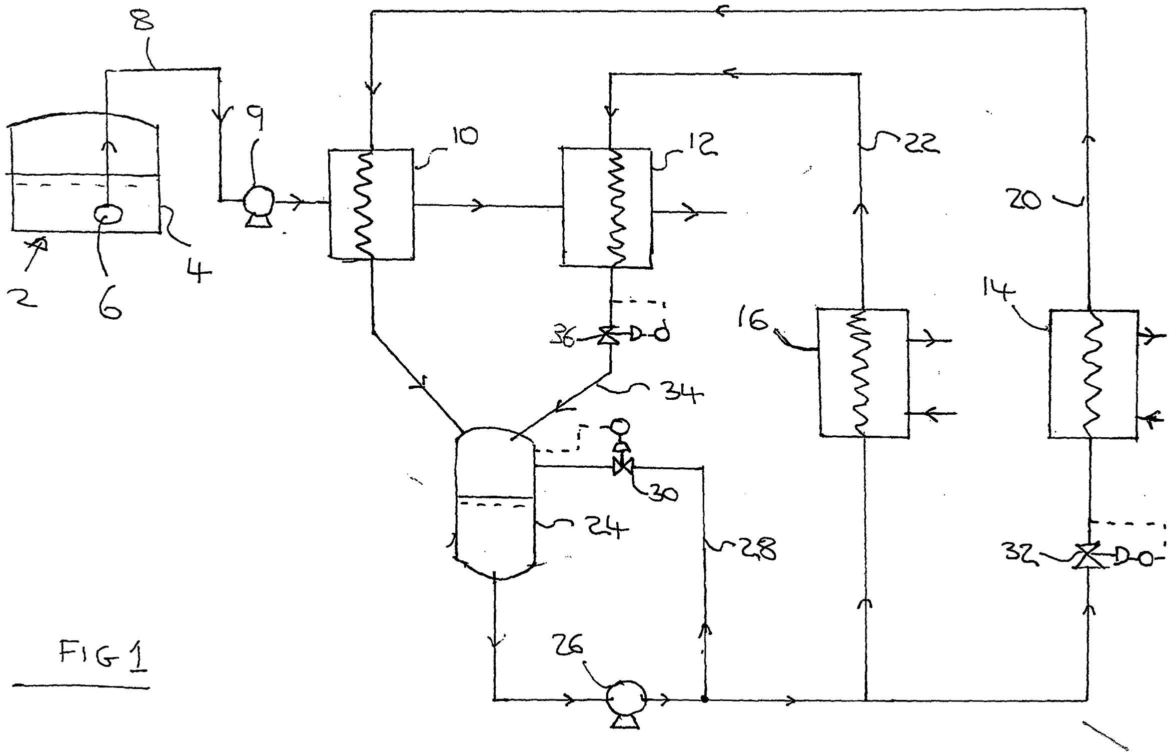

FIG 1

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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 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] 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 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.

[0007] 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.

[0008] The apparatus according to the invention preferably additionally comprises a liquid pump for taking liquid heat exchange fluid from the common collection vessel and for circulating it through the first and second endless heat exchange circuits.

[0009] 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.

[0010] 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.

[0011] 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.

[0012] 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.

[0013] Preferably the pressure in the ullage space of the common collection vessel is essentially the condensing pressure of the first endless circuit exchange fluid.

[0014] 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 above minus 40°C but below + 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, 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.

[0015] The method and apparatus according to the invention will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 is a general schematic flow diagram of an LNG vaporisation apparatus; and

[0016] 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.

[0017] 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.

[0018] 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.

[0019] 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.

[0020] The necessary heat for the first and second supplementary heat exchangers 14 and 16 may be provided by any convenient supplementary heat exchange medium:

[0021] 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.

[0022] 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.

[0023] 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 bilge tanks 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, 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 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 seawater 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.

[0024] 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 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 higher, 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.

[0025] 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.

[0026] 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 to decreased 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 at higher thermal loads.

[0027] 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.

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 both comprise propane.

7. 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.

8. A method according to claim 7, wherein the seawater flows in a closed circuit.

9. A method according to claim 7, wherein the seawater flows in an open circuit.

10. 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 second 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.

11. Apparatus as claimed in claim 10, wherein the first and second endless heat exchange circuits have a common liquid collection vessel.

12. Apparatus according to claim 11, 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.

13. Apparatus according to any one of claims 10 to 12, 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.

14. Apparatus according to claim 13, when dependent from claim 12, 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.

15. Apparatus according to any of claims 10 to 14, 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.

16. Apparatus according to Claim 15, 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.

17. Apparatus according to claim 15 or claim 16, when dependent from claim 11, 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.

18. Apparatus according to any one of claims 12 to 17 , when dependent from claim 11, 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.

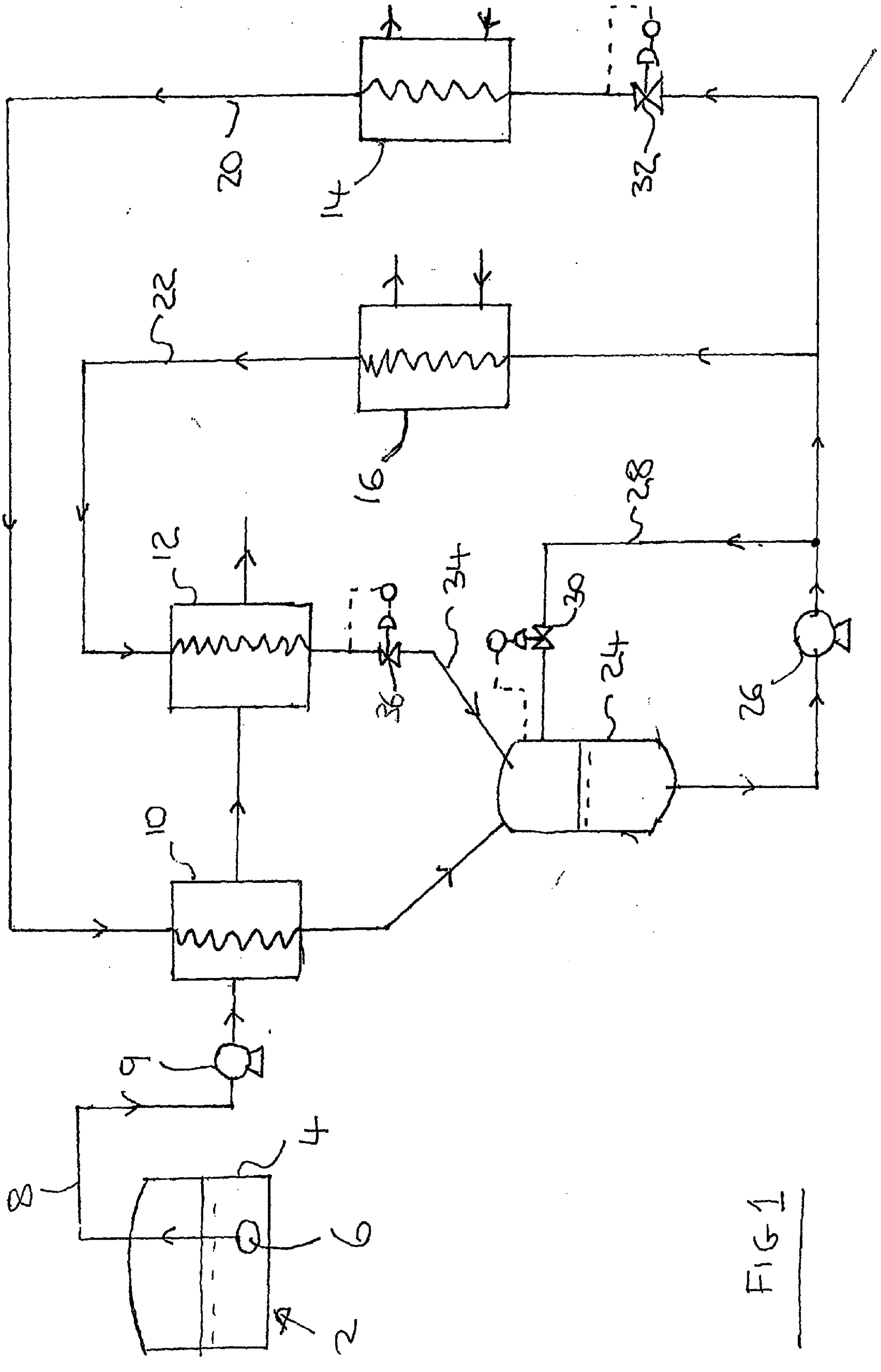

FIG 1

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EUROPEAN SEARCH REPORT

Application Number
EP 08 35 2015

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The present search report has been drawn up for all claims

3

Place of search	Date of completion of the search	Examiner
Munich	10 October 2008	Ott, Thomas

CATEGORY OF CITED DOCUMENTS

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