(19) Europäisches Patentamt / European Patent Office / Office européen des brevets

(11) EP 2 765 281 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
13.08.2014 Bulletin 2014/33

(51) Int Cl.:
F01K 23/02 *(2006.01)*

(21) Application number: **13000615.8**

(22) Date of filing: **07.02.2013**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME

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(54) A rankine cycle apparatus

(57) The apparatus comprises:
- a Rankine cycle circuit including at least first heating means (1.3) for heating a fluid and second heating means (1.4) for heating the fluid once heated by the first heating means (1.3); and
- a refrigerating thermal machine circuit, a portion of which is connected to or forms part of the second heating means (1.4) for transferring the heat and/or calorific energy of the fluid circulating therein to the fluid of the Rankine cycle circuit.

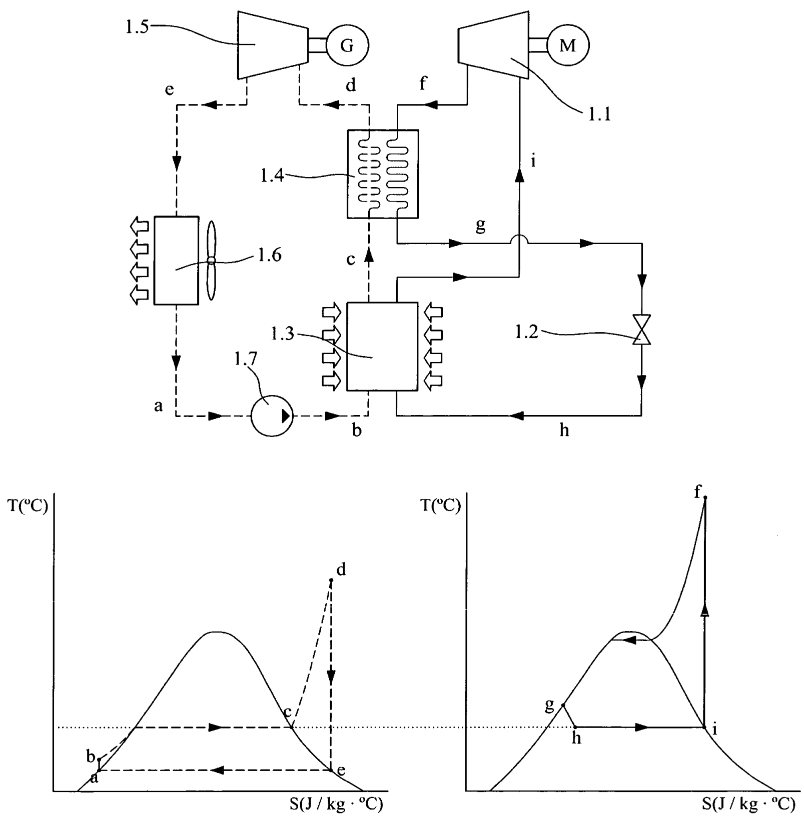

Figure 1

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Description

Field of the art

[0001] The present invention generally relates to a Rankine cycle apparatus comprising a Rankine cycle circuit and a refrigerating thermal machine circuit, where the latter is used for heating a fluid circulating through the Rankine cycle circuit, and more particularly to an apparatus where said heating is an additional heating performed after a main heating.

Prior State of the Art

[0002] JP2012112369 discloses a system for saving energy in an air conditioner system of a vehicle, where a heat pump is used for heating fluid circulating through a Rankine cycle circuit in a heat exchanger. Said heat exchanger is the only heating device included in the Rankine cycle circuit.

[0003] US8302399B1 discloses a waste heat recovery system comprising a Rankine cycle circuit having first heating means and second heating means, sequentially arranged between a pump an a turbine. The first heating means perform a preheating of the fluid coming from the pump by means of a thermal transfer from the fluid circulating through a plurality of refrigerating cycles, arranged in parallel branches, in the form of a plurality of charge air coolers in communication with a plurality of turbocharger stages.

[0004] JP2008008224 discloses a waste heat management apparatus of an internal combustion engine, which comprises a Rankine cycle circuit including first and second heating means in the form of respective heat exchangers, where the first of the heat exchangers uses as heat source for transferring heat to the fluid of the Rankine cycle a heated fluid used for refrigerating a combustion engine, while the second one uses as heat source heat of suction air pressurized by supercharger of the engine, also known as intercooler. None of the heat exchangers uses as heat source a refrigerating thermal machine circuit.

[0005] WO2009107828A1 discloses a Rankine cycle circuit including a first parallel heat exchanger for heating a fluid and a second parallel heat exchanger for heating the fluid once heated by the first parallel heat exchanger, and a refrigerating thermal machine circuit a portion of which is connected to a first path of the first parallel heat exchanger for transferring the heat and/or calorific energy of the fluid circulating therein to the fluid of the Rankine cycle circuit which circulates through a second path of the first parallel heat exchanger.

[0006] The fact of using the refrigerating thermal machine circuit as a heat source for the first or main heating means of a Rankine cycle circuit has many drawbacks, mainly associated to the difficulties found for arranging and controlling additional elements prior to the first heating means in the Rankine cycle circuit, such as regenerative stages where the control of the temperature of the fluid tapped from the turbine is a very delicate issue, or those additional elements affecting directly the first heating means, as is the case of some reheating cycles passing there through. Thus, if some regenerating stages were introduced into the Rankine cycle circuit of WO2009107828A1, the efficiency achieved by said introduction and the overall performance of the system would be both low, in comparison with the apparatus of the present invention, as will be expounded below.

[0007] The present inventor doesn't know any proposal which teaches the use of a refrigerating thermal machine circuit as a heat source for a second or further heating means of a Rankine cycle circuit arranged after a first or main heating means.

Description of the Invention

[0008] It is necessary to offer an alternative to the state of the art which covers the gaps found therein, by the provision of a Rankine cycle apparatus more efficient than the ones known in the state of the art, and which doesn't have the drawbacks above indicated with respect to the apparatuses which use a refrigerating thermal machine circuit as a heat source for the first or main heating means of a Rankine cycle circuit.

[0009] To that end, the present invention concerns to a Rankine cycle apparatus, comprising:

- a Rankine cycle circuit including at least first heating means for heating a fluid and second heating means for heating the fluid once heated by the first heating means; and
- a refrigerating thermal machine circuit, a portion of which is connected to or forms part of one of said first and second heating means for transferring the heat and/or calorific energy of the fluid circulating therein to the fluid of the Rankine cycle circuit.

[0010] Contrary to the known Rankine cycle apparatuses, in the one proposed by the present invention, in a characteristic manner, said heating means to which said portion of said refrigerating thermal machine circuit is connected is said second heating means, the latter being, therefore, a joint point of both circuits: the Rankine cycle circuit and the refrigerating thermal machine circuit.

[0011] The performance of any thermodynamic cycle is mainly dependant on the maximum and minimum temperatures of the cycle, therefore the greater the difference between these temperatures the greater the performance of the cycle.

[0012] In a conventional Rankine cycle the maximum temperature of the cycle is obtained in the main heater, and in a Rankine cycle with pre-heating, such as the one of WO2009107828A1, the maximum temperature is obtained in the heater which is not joined to the refrigerating thermal machine, while in one with post-heating by means of a refrigerating thermal machine, i.e. in the apparatus of the present invention, the maximum temperature of the cycle is obtained in the second heater, which is joined to the refrigerating thermal machine.

[0013] Therefore, for the same heat source, if the different types of Rankine cycles are compared, the cycle in which the maximum temperature is higher is the cycle with post-heating by means of a refrigerating thermal machine, i.e. the one of the present invention, thus providing the highest performance, due also to a good optimization thereof.

[0014] Moreover, it can be theoretically justified that, for certain conditions, the performance of a heat engine is increased if part of the heat source which makes the engine work is provided by a refrigerating thermal machine driven by part of the kinetic energy produced by the heat engine itself. This is the case of the apparatus of the present invention, with a higher efficiency than that of the apparatus of WO2009107828A1.

[0015] By using, according to the present invention, a refrigerating thermal machine circuit as heat source for the second heating means of the Rankine cycle circuit, the efficiency of the whole cycle is increased, while the arrangement and control of additional elements prior or affecting the first heating means is at least not made more difficult than in conventional Rankine cycles not using a refrigerating cycle as a heat source, and much easier and advantageous than in those apparatuses which use a refrigerating cycle as a heat source for the first or main heating means.

[0016] It must be understood that, in the present invention, the terms second heating means refer to any heating means arranged after the main heating means of the Rankine cycle circuit, whatever the number of heating means included in the Rankine cycle circuit is, i.e. if the Rankine cycle circuit has, for example, a main heating means and three further heating means, arranged between the main heating means and the vapour expander, the second heating means can be any of said three further heating means, or even more than one of them.

[0017] Depending on the embodiment, said refrigerating thermal machine circuit is a vapour compression cycle circuit or constitutes a heat pump.

[0018] For a preferred embodiment, the apparatus of the present invention constitutes a heat engine, i.e. an apparatus that transforms a temperature difference into kinetic energy, where the latter can be transformed afterwards into electrical energy by means of other systems.

[0019] The industrial applications of the present invention are of a wide variety, including, for example:

- Recovery of energy from residual heat in different industrial processes.
- Recovery of heat lost in the exhaust pipes of motor vehicles.
- As a motor in any kind of thermal centrals, such as: nuclear centrals, combined-cycle centrals, geothermal centrals, thermosolar centrals, etc.

[0020] For an embodiment of the apparatus of the invention, the second heating means comprises a heat exchanger having a first path fluidically communicating the output of the first heating means with the input of at least one vapour expander (such as a turbine) of the Rankine cycle, and a second path connected to or constituted by said portion of the refrigerating thermal machine circuit, such that the heat and/or calorific energy of the fluid circulating through the second path is transferred to the one circulating through the first path.

[0021] The heat exchanger can be any of the already known heat exchangers, although the use of a counterflow heat exchanger is preferred.

[0022] According to an embodiment of the invention, the refrigerating thermal machine circuit has a further use with respect to the Rankine cycle circuit, particularly related to the cooling of the fluid circulating between the vapour expander and the first heating means. To that end, another portion of the refrigerating thermal machine circuit is connected to a cooling device, arranged in the Rankine cycle circuit, in a segment between the vapour expander and the first heating means, for cooling the fluid circulating therein.

[0023] For different variants of said embodiment, said cooling device is arranged previously or after a condenser of the Rankine cycle circuit, for providing a two-stage cooling of the fluid exiting the vapour expander: the one provided by the cooling device and the one provided by the condenser itself.

[0024] For a preferred embodiment, the cooling device is a heat exchanger having a first path connected to or constituted by said another portion of the refrigerating thermal machine circuit and a second path constituted by said segment of the Rankine cycle circuit, such that the heat and/or calorific energy of the fluid circulating through the second path is transferred to the one circulating through the first path.

[0025] For some embodiments, the refrigerating thermal machine circuit of the apparatus of the present invention is configured and arranged for refrigerating at least part of the first heating means and/or of a heating device of the refrigerating thermal machine circuit.

[0026] According to other embodiments, the Rankine cycle circuit is a regenerative Rankine cycle circuit or a Rankine cycle circuit with reheating including two or more vapour expanders, or a combination thereof.

[0027] If some regenerating stages were introduced into the Rankine cycle circuit of WO2009107828A1, the efficiency achieved by said introduction and the overall performance of the system would be both much lower than the ones obtained by the apparatus of the present invention for said embodiment including a regenerative Rankine cycle circuit.

[0028] Any combination of the elements and arrangements of the Rankine cycle circuit and of the refrigerating thermal machine circuit described above for some embodiments, can be done for other embodiments, such as, for example the inclusion in the Rankine cycle circuit of regenerative cycles and reheating cycles. Some of the possible combinations will be described below with reference to the accompanying drawings.

[0029] The apparatus of the present invention comprises, for an embodiment, a plurality of sensors arranged for detecting at least temperature (and optionally also other parameters, such as pressure) at different points of the Rankine cycle circuit and of the refrigerating thermal machine circuit, and control means configured and arranged for receiving the temperature readings performed by said sensors and for controlling valve devices and/or the operation of at least some of the elements (such as the output pressure of pumps or compressors) of the Rankine cycle circuit and of the refrigerating thermal machine circuit as a function of at least said temperature readings.

Brief Description of the Drawings

[0030] The previous and other advantages and features will be more fully understood from the following detailed description of embodiments, with reference to the attached drawings (some of which have already been described in the Prior State of the Art section), which must be considered in an illustrative and non-limiting manner, in which:

Figure 1 shows the apparatus of the present invention for an embodiment for which the apparatus comprises: 1.1 Vapour compressor, 1.2 Expansion valve, 1.3 Main heater, 1.4 Second heater, 1.5 Vapour turbine, 1.6 Condenser and 1.7 Pump, together with two respective T-S diagrams for both circuits included in the apparatus, where T is temperature and S entropy.

Figure 2 shows the apparatus of the present invention, and also two T-S diagrams, for another embodiment for which the apparatus comprises: 2.1 Vapour compressor, 2.2 Expansion valve, 2.3 Main heater of the secondary circuit, 2.4 Main heater of the primary circuit, 2.5 Second heater, 2.6 Vapour turbine, 2.7 Condenser and 2.8 Pump.

Figure 3 shows the apparatus of the present invention, and also two T-S diagrams, for another embodiment for which the apparatus comprises: 3.1 Vapour compressor, 3.2 Expansion valve, 3.3 Main heater of the secondary circuit, 3.4 Main heater of the primary circuit, 3.5 Second heater, 3.6 Vapour turbine, 3.7 Condenser, 3.8 Low pressure pump and 3.9 Open heater and 3.10 High pressure pump.

Figure 4 shows the apparatus of the present invention, and the two T-S diagrams, for a further embodiment for which the apparatus comprises: 4.1 Vapour compressor, 4.2 Expansion valve of the primary circuit, 4.3 Main heater of the secondary circuit, 4.4 Main heater of the primary circuit, 4.5 Second heater, 4.6 Vapour turbine, 4.7 Condenser, 4.8 Expansion valve of the regenerative circuit, 4.9 Pump and 4.10 Closed heater.

Figure 5 shows the apparatus of the present invention, and also two T-S diagrams, for an embodiment for which the apparatus comprises: 5.1 Gas compressor, 5.2 Motor, 5.3 Main heater, 5.4 Second heater, 5.5 Vapour turbine, 5.6 Condenser and 5.7 Pump.

Figure 6 shows the apparatus of the present invention, and also two T-S diagrams, for another embodiment for which the apparatus comprises: 6.1 Gas compressor, 6.2 High pressure motor, 6.3 Low pressure motor, 6.4 Main heater, 6.5 Second heater, 6.6 Vapour turbine, 6.7 Condenser and 6.8 Pump.

Figure 7 shows the apparatus of the present invention, and also two T-S diagrams, for an embodiment for which the apparatus comprises: 7.1 Gas compressor, 7.2 Motor, 7.3 Main heater, 7.4 Second heater, 7.5 Vapour turbine, 7.6 Cooler, 7.7 Condenser and 7.8 Pump.

Figure 8 shows the apparatus of the present invention, and the T-S diagrams for the circuits included therein, for a further embodiment for which the apparatus comprises: 8.1 Gas compressor, 8.2 Motor, 8.3 Main heater, 8.4 Second heater, 8.5 Vapour turbine, 8.6 Condenser, 8.7 Cooler and 8.8 Pump.

Figure 9 shows the apparatus of the present invention, and also two T-S diagrams, for an embodiment for which the apparatus comprises: 9.1 Gas compressor, 9.2 Motor, 9.3 Main heater, 9.4 Second heater, 9.5 Vapour turbine, 9.6 Cooler, 9.7 Condenser, 9.8 Expansion valve of the regenerative circuit, 9.9 Pump and 9.10 Closed heater.

Figure 10 shows the apparatus of the present invention, and the two T-S diagrams, for an embodiment for which the apparatus comprises: 10.1 Gas compressor, 10.2 Motor, 10.3 Main heater, 10.4 Second heater, 10.5 High pressure vapour turbine, 10.6 Low pressure vapour turbine, 10.7 Condenser and 10.8 Pump.

Figure 11 shows the apparatus of the present invention, and also two T-S diagrams, for an embodiment for which the apparatus comprises: 11.1 Vapour compressor, 11.2 Expansion valve, 11.3 Main heater of the secondary circuit, 11.4 Main heater of the primary circuit, 11.5 Second heater, 11.6 Vapour turbine, 11.7 Condenser and 11.8 Pump.

Detailed Description of Several Embodiments

[0031] The appended Figures show different arrangements of the Rankine cycle apparatus of the present invention for corresponding different embodiments, all of them having in common that the apparatus is a heat engine and comprises:

- a Rankine cycle circuit, or primary circuit, depicted in dotted line, including at least first heating means or main heater 1.3, 2.4, 3.4, 4.4, 5.3, 6.4, 7.3, 8.3, 9.3, 10.3, 11.4, such as a vapour generator, for heating a fluid and second heating means 1.4, 2.5, 3.5, 4.5, 5.4, 6.5, 7.4, 8.4, 9.4, 10.4, 11.5, in the form of a counter-flow heat exchanger, for heating the fluid once heated by the first heating means 1.3, 2.4, 3.4, 4.4, 5.3, 6.4, 7.3, 8.3, 9.3, 10.3, 11.4; and

- a refrigerating thermal machine circuit, or secondary circuit, depicted in solid line, a portion of which is connected to or forms part of the second heating means 1.4, 2.5, 3.5, 4.5, 5.4, 6.5, 7.4, 8.4, 9.4, 10.4, 11.5 for transferring the heat and/or calorific energy of the fluid circulating therein to the fluid of the Rankine cycle circuit.

[0032] Figure 1 shows a basic arrangement of the apparatus of the invention, where there is only one main heater 1.3 for both circuits, where the secondary circuit is a vapour compression circuit.

[0033] The apparatus of Figure 1 works as follows:

The description of the operation primary circuit, i.e. of the Rankine cycle circuit, can be started at point "a" shown at the left T-S diagram of Figure 1. First, fluid circulates through pump 1.7 increasing its pressure until point "b". Then, it enters the main heater 1.3 where is heated until point "c". Next, the fluid is further heated in the second heater 1.4, by entering in a first path of the illustrated counter-flow heat exchanger, until point "d". Then, the fluid goes to the vapour turbine 1.5 where the heat of the fluid is transformed into mechanical energy, the fluid exiting the vapour turbine 1.5 at point "e". Finally, in this circuit, the fluid is introduced into condenser 1.6 where heat which cannot be further exploited is lost and when exiting the condenser 1.6 the fluid is again at point "a".

[0034] Starting the description of the operation of the secondary circuit, i.e. the refrigerating thermal machine circuit, at point "i" of the right T-S diagram of Figure 1, fluid enters into the vapour compressor 2.1 where is compressed increasing thus its temperature and energy, exiting at point "f". Next the fluid enters a second path of the heat exchanger which constitutes the second heater 1.4 where is cooled until point "g", while heating the first path of the heat exchanger 1.4, i.e. the fluid of the primary circuit from "c" to "d". Next, the fluid passes through the expansion valve 1.2 where it mainly loses pressure and temperature until point "h", in order to be able to be compressed afterwards. Finally, it enters the main heater 1.3 where the fluid increases its energy without increasing its temperature as it happens in a phase change, and when exiting the main heater 1.3 the fluid is again at point "i".

[0035] In this apparatus, calorific energy is introduced into the main heater 1.3 and mechanical energy is introduced into the vapour compressor 1.1 and into the pump 1.7, while mechanical energy is extracted from the vapour turbine 1.5 and calorific energy is lost at condenser 1.6. Therefore, the performance of the apparatus is calculated as the ratio of the energy extracted from the vapour turbine 1.5 to the sum of the energies introduced into the main heater 1.3, the vapour compressor 1.1 and the pump 1.7.

[0036] Figure 2 differs from Figure 1 in that in the embodiment of Figure 2 each circuit has its own main heater, 2.4 for the Rankine cycle circuit and 2.3 for the refrigerating thermal machine circuit, the overall operation being the same that for the embodiment of Figure 1.

[0037] Figure 3 differs from Figure 1 in that in the arrangement of Figure 2 the Rankine cycle circuit is a regenerative Rankine cycle circuit with an open heater 3.9 placed between a low pressure pump 3.8 and a high pressure pump 3.10. Fluid is tapped from an intermediate temperature point of the turbine 3.6 and introduced into the open heater 3.9 at point "g", in order to heat fluid coming from the low pressure pump 3.8 from "b" to "c". Next the fluid is pumped by high pressure pump 3.10 to enter the main heater 3.4. The rest of the operation of the circuits is the same than in Figure 2, corresponding the points "c", "d", "e" and "f" to "i" of Figure 2 to, respectively, the points "e", "f", "h" and "i" to "l" of Figure 3.

[0038] Regarding Figure 4, it shows an arrangement of the apparatus of the present invention which is almost identical to that of Figure 3 but where the regenerative cycle includes a closed heater 4.10 instead of an open heater. In this case, fluid is tapped from an intermediate temperature point of the turbine 4.6 and introduced into a first path of the closed heater 4.10 at point "f", in order to heat fluid coming from the pump 4.9 and which circulates, from "b" to "c", through the second path of the heat exchanger constituting the closed heater 4.10. When exiting the first path of the heat exchanger 4.10 at "g" fluid passes through an expansion valve 4.8 losing pressure and temperature until "h", where it enters the condenser 4.7, thus mixing with the fluid coming from "j" into the fluid outputting the condenser 4.7 at "a". At "c" the fluid enters the main heater 4.4, being the rest of the operation of the circuits the same than in Figure 2, corresponding the points "c", "d", "e" and "f" to "i" of Figure 2 to, respectively, the points "d", "e", "i" and "j" to "m" of Figure 4.

[0039] The embodiment of the apparatus of the present invention shown in Figure 5 is very similar to the one of Figure 1, differing therefrom in that the secondary circuit is not a vapour compression cycle but a heat pump. The operation of this circuit is the following:

Starting form point "i", gas enters compressor 5.1 where it increases its pressure, temperature and energy. Then, at "f", it enters the first path of the heat exchanger constituting the second heater 5.4, where gas is cooled while heating the second path of the heat exchanger 5.4, i.e. the fluid of the Rankine cycle circuit, from "c" to "d". Next, this gas is introduced into motor 5.2 in order it loses its heat by its transforming into mechanical energy. Finally, the fluid at "h" enters the main heater 5.3 where is heated up to "i". The operation of the Rankine cycle circuit is the same than in Figure 1.

[0040] The energetic distribution of the apparatus of the present invention for the embodiment of Figure 4 is the following:

Thermal energy is introduced into main heater 5.3 and mechanical energy is introduced into compressor 5.1 and into pump 5.7.

[0041] Mechanical energy is extracted from the vapour turbine 5.5 and from the motor 5.2, while thermal energy is lost in the condenser 5.6.

[0042] The performance is, therefore, the ratio between the sum of the extracted mechanical energy to the sum of all energy introduced.

[0043] The embodiment of Figure 6 differs from the one of Figure 5 in that, instead of only one motor, the secondary circuit includes two motors: a high pressure motor 6.2 and a low pressure motor 6.3 in a reheating cycle. I.e., once gas exits the high pressure motor 6.2 at "h" it enters the main heater 6.4 where is heated until point "i". Next, instead of going to the compressor 6.1, it enters the low pressure motor 6.3, where it still loses more pressure and temperature. Then, gas at "j" passes again through the main heater 6.4 where is heated again until point "k", and then it enters gas compressor 6.1. An increase in the overall performance is thus achieved.

[0044] When observing the right T-S diagram of Figure 5, it can be seen that point "h" has a lower temperature than the lowest temperature of the primary circuit, as shown in the left T-S diagram of said Figure. This lower temperature can be used for cooling the primary circuit and, thus, improve its performance.

[0045] The arrangement of Figure 7 provides that use, by taking profit of the mentioned phenomenon, as when gas exits the motor 7.2 at "i" it is introduced into cooler 7.6, particularly into a first path of the heat exchanger constituting said cooler 7.6, where said gas is heated form point "i" until "j", while in the primary circuit the fluid circulating through the second path of the heat exchanger 7.6 loses energy from point "e" until point "f" where it enters the condenser 7.7, and then is pumped form "a" to "b" to enter the main heater 7.3, into which fluid at "j" also enters.

[0046] The rest of the operation is the same as explained regarding Figure 5, corresponding the points "f", "g", "h" and "i" of Figure 5 to, respectively, the points "g", "h", "i" and "k" of Figure 7.

[0047] The implementation of the apparatus of the present invention shown in Figure 8 is very similar to the one of Figure 7, with the difference that the cooler 8.7 is not arranged after the vapour turbine 8.5 but after the condenser 8.6 in the primary circuit, which, according to the left T-S diagram of Figure 8, provides a loss of energy for the fluid of the primary circuit from "f" to "a".

[0048] Figure 9 shows the apparatus of the present invention for another embodiment similar to the one of Figure 7 but with the addition, in the primary circuit, of a regenerative Rankine circuit with a closed heater 9.10.

[0049] The operation of the circuit can be easily understood from the above description of the arrangement of Figure 7, regarding the secondary circuit, particularly regarding the cooler 9.6 (7.6 in Figure 7), and the arrangement of Figure 4, regarding the primary circuit, particularly regarding the regenerative cycle operation.

[0050] Points "f" to "k" of Figure 7 correspond to, respectively, points "j" to "o" of Figure 9, while points "a" to "i" of Figure 4 correspond to points "a" to "i" of Figure 9.

[0051] Regarding the arrangement of Figure 10, this one differs from the arrangement of Figure 5 in that the Rankine cycle circuit includes two vapour turbines 10.5 and 10.6, and the heat exchanger 10.4 comprises a third path (which is also heated by heat and/or calorific energy transfer from the fluid of the secondary circuit circulating from "i" to "j") fluidically communicating a further output of the main heater 10.3, at "c", with the input of the high pressure vapour expander 10.5, at "d", the latter having an output connected to an intermediate temperature input of the main heater 10.3, at "e", where the fluid is heated again exiting at "f", then being further heated in the heat exchanger 10.4, exiting at "g", and then entering the low pressure vapour turbine 10.6.

[0052] With this arrangement, mechanical energy is extracted, at the Rankine cycle circuit, from two vapour turbines, although the temperature of the fluid entering the vapour turbines 10.5 and 10.6 is lower than the one of the fluid entering vapour turbine 5.5, thus the mechanical energy obtained is lower than the one obtained with the vapour turbine 5.5 of the arrangement of Figure 5.

[0053] Points "f" to "i" of Figure 5 correspond to, respectively, points "i" to "l" of Figure 10, while points "a" to "i" of Figure 4 correspond to points "a" to "d" and "e" of Figure 5 correspond to, respectively, points "a" to "d" and "h" of Figure 10, although with different temperature values

[0054] Figure 11 shows an arrangement of the apparatus of the present invention almost identical to the one of Figure 2, but with the difference that in this case the main heater of the secondary circuit 11.3 is refrigerated with environment air.

[0055] As stated in a previous section, any other combination of the elements and arrangements of the Rankine cycle circuit and of the refrigerating thermal machine circuit shown in the appended Figures can be done for other embodiments (not illustrated) of the apparatus of the present invention, such as, for example, the inclusion in the Rankine cycle circuit of regenerative cycles (with open or closed heaters) and/or reheating cycles, of any number of vapour turbines and of coolers taking profit of the fluid of the secondary circuit, and/or the use, in the refrigerating circuit, of common main heaters with the Rankine circuit or of independent heaters, and/or its constitution as heat pump or as a vapour compression cycle, etc.

[0056] Therefore, a person skilled in the art could introduce changes and modifications in the embodiments described without departing from the scope of the invention as it is defined in the attached claims.

Claims

1. A Rankine cycle apparatus, comprising:

    - a Rankine cycle circuit including at least first heating means (1.3, 2.4, 3.4, 4.4, 5.3, 6.4, 7.3, 8.3, 9.3, 10.3, 11.4) for heating a fluid and second heating means (1.4, 2.5, 3.5, 4.5, 5.4, 6.5, 7.4, 8.4, 9.4, 10.4, 11.5) for heating the fluid once heated by the first heating means (1.3, 2.4, 3.4, 4.4, 5.3, 6.4, 7.3, 8.3, 9.3, 10.3, 11.4); and
    - a refrigerating thermal machine circuit, a portion of which is connected to or forms part of one of said first (1.3, 2.4, 3.4, 4.4, 5.3, 6.4, 7.3, 8.3, 9.3, 10.3, 11.4) and second (1.4, 2.5, 3.5, 4.5, 5.4, 6.5, 7.4, 8.4, 9.4, 10.4, 11.5) heating means for transferring the heat and/or calorific energy of the fluid circulating therein to the fluid of the Rankine cycle circuit;

    wherein the apparatus is **characterised in that** said heating means to which said portion of said refrigerating thermal machine circuit is connected is said second heating means (1.4, 2.5, 3.5, 4.5, 5.4, 6.5, 7.4, 8.4, 9.4, 10.4, 11.5).

2. The apparatus of claim 1, wherein it constitutes a heat engine.

3. The apparatus of claim 1 or 2, wherein said second heating means (1.4, 2.5, 3.5, 4.5, 5.4, 6.5, 7.4, 8.4, 9.4, 10.4, 11.5) comprises a heat exchanger having a first path fluidically communicating the output of said first heating means (1.3, 2.4, 3.4, 4.4, 5.3, 6.4, 7.3, 8.3, 9.3, 10.3, 11.4) with the input of at least one vapour expander (1.5, 2.6, 3.6, 4.6, 5.5, 6.6, 7.5, 8.5, 9.5, 10.5, 10.6, 11.6) of the Rankine cycle, and a second path connected to or constituted by said portion of the refrigerating thermal machine circuit, such that the heat and/or calorific energy of the fluid circulating through the second path is transferred to the one circulating through the first path.

4. The apparatus of claim 3, wherein said vapour expander (1.5, 2.6, 3.6, 4.6, 5.5, 6.6, 7.5, 8.5, 9.5, 10.5, 10.6, 11.6) is a turbine.

5. The apparatus of any of claims 3 or 4, wherein another portion of said refrigerating thermal machine circuit is connected to a cooling device (7.6, 8.7), arranged in said Rankine cycle circuit, in a segment between said vapour expander (7.5, 8.5) and said first heating means (7.3, 8.3), for cooling the fluid circulating therein.

6. The apparatus of claim 5, wherein said cooling device (7.6, 8.7) is arranged previously or after a condenser (7.7, 8.6) of the Rankine cycle circuit, for providing a two-stage cooling of the fluid exiting the vapour expander (7.5, 8.5).

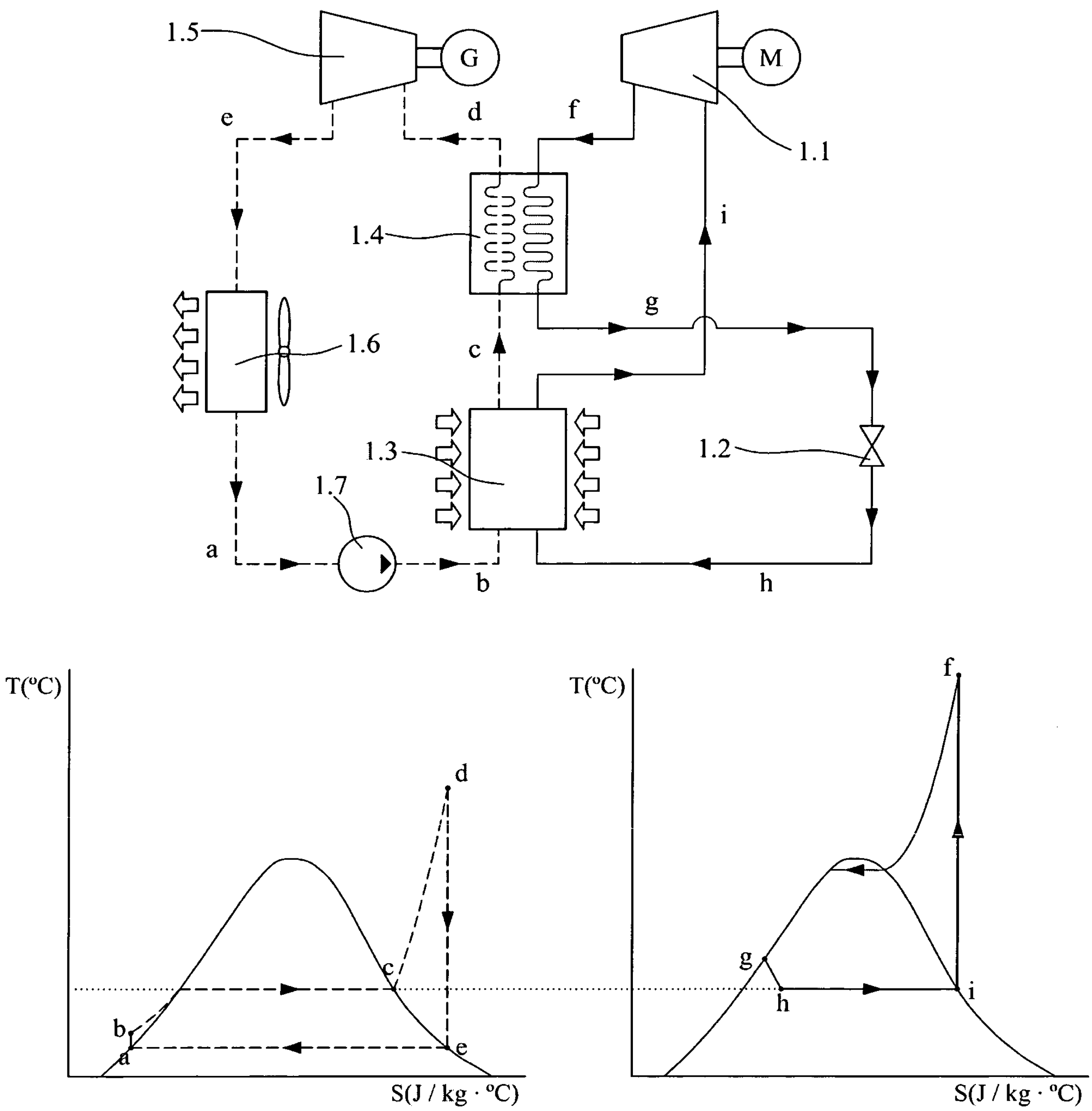
7. The apparatus of claim 5 or 6, wherein said cooling device (7.6, 8.7) is a heat exchanger having a first path connected to or constituted by said another portion of the refrigerating thermal machine circuit and a second path constituted by said segment of the Rankine cycle circuit, such that the heat and/or calorific energy of the fluid circulating through the second path is transferred to the one circulating through the first path.

8. The apparatus of any of the previous claims, wherein said refrigerating thermal machine circuit is a vapour compression cycle circuit or constitutes a heat pump.

9. The apparatus of any of any of the previous claims, wherein said refrigerating thermal machine circuit is configured and arranged for refrigerating at least part of said first heating means (1.3, 2.4, 3.4, 4.4, 5.3, 6.4, 7.3, 8.3, 9.3, 10.3, 11.4) and/or of a heating device (2.3, 3.3, 4.3, 11.3) of the refrigerating thermal machine circuit.

10. The apparatus of any of the previous claims, wherein said Rankine cycle circuit is a regenerative Rankine cycle circuit or a Rankine cycle circuit with reheating including two or more vapour expanders (10.6, 10.5), or a combination thereof.

11. The apparatus of any of the previous claims, comprising a plurality of sensors arranged for detecting at least temperature at different points of the Rankine cycle circuit and of the refrigerating thermal machine circuit, and control means configured and arranged for receiving the temperature readings performed by said sensors and for controlling valve devices and/or the operation of at least some of the elements of the Rankine cycle circuit and of the refrigerating thermal machine circuit as a function of said temperature readings.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d
f
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1.4
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1.6
c
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1.2
1.7
a
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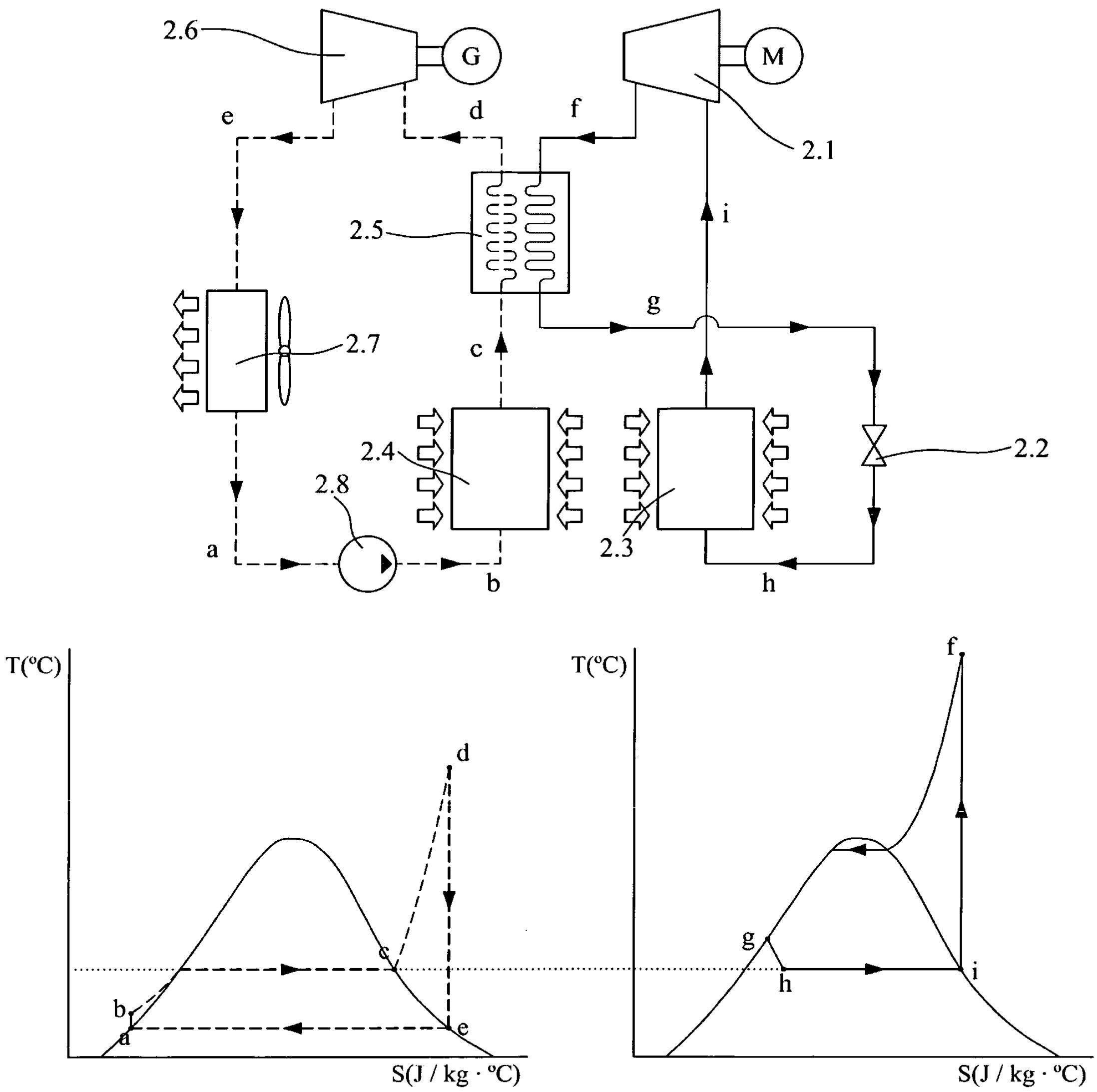
h
T(ºC)
d
c
b
a
e
S(J / kg · ºC)
T(ºC)
f
g
h
i
S(J / kg · ºC)

Figure 1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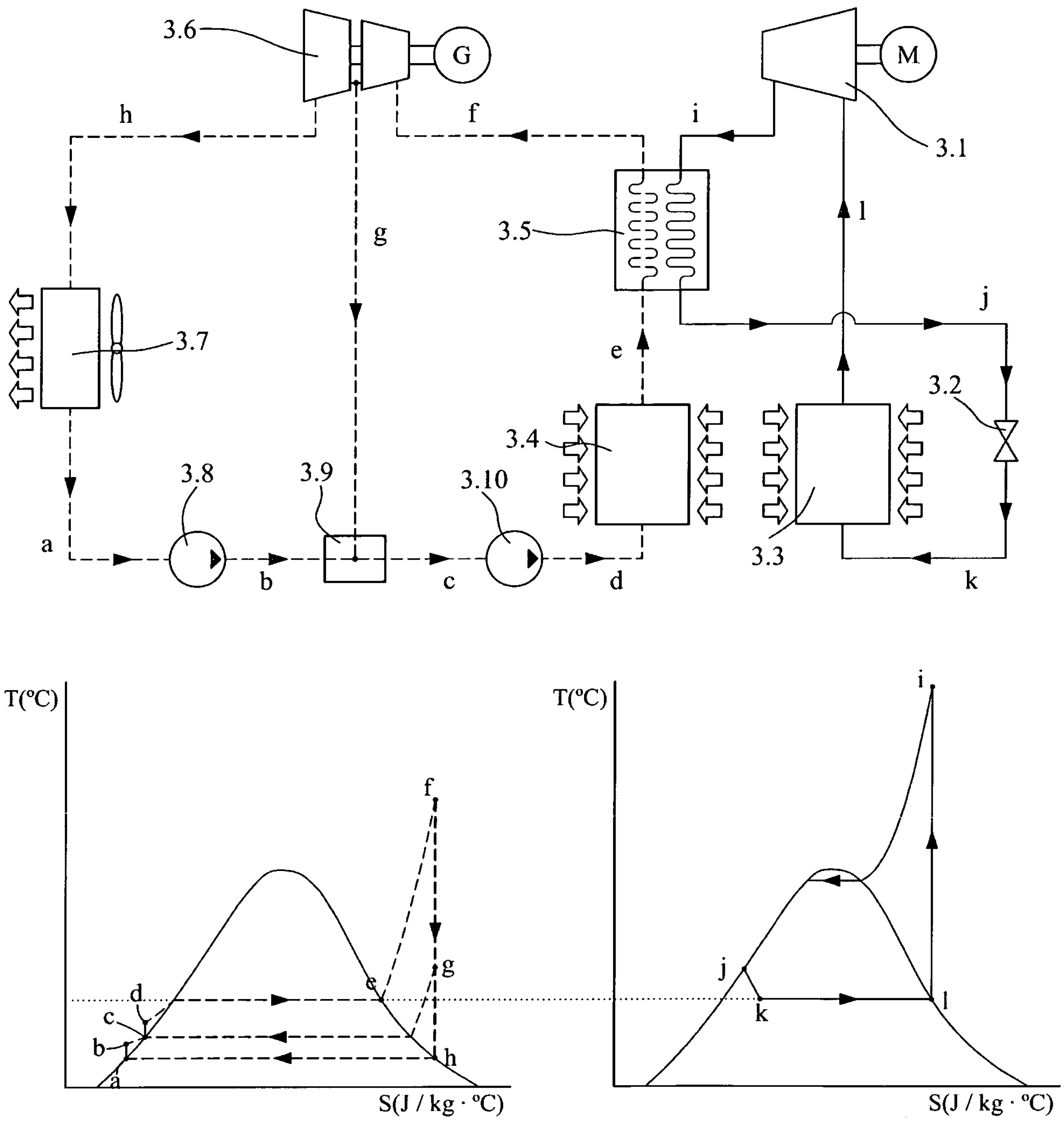
2.3
2.2
a
b
h
T(ºC)
d
c
b
a
e
S(J / kg · ºC)
T(ºC)
f
g
h
i
S(J / kg · ºC)

Figure 2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f
i
M
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g
3.5
l
j
3.7
e
3.2
3.4
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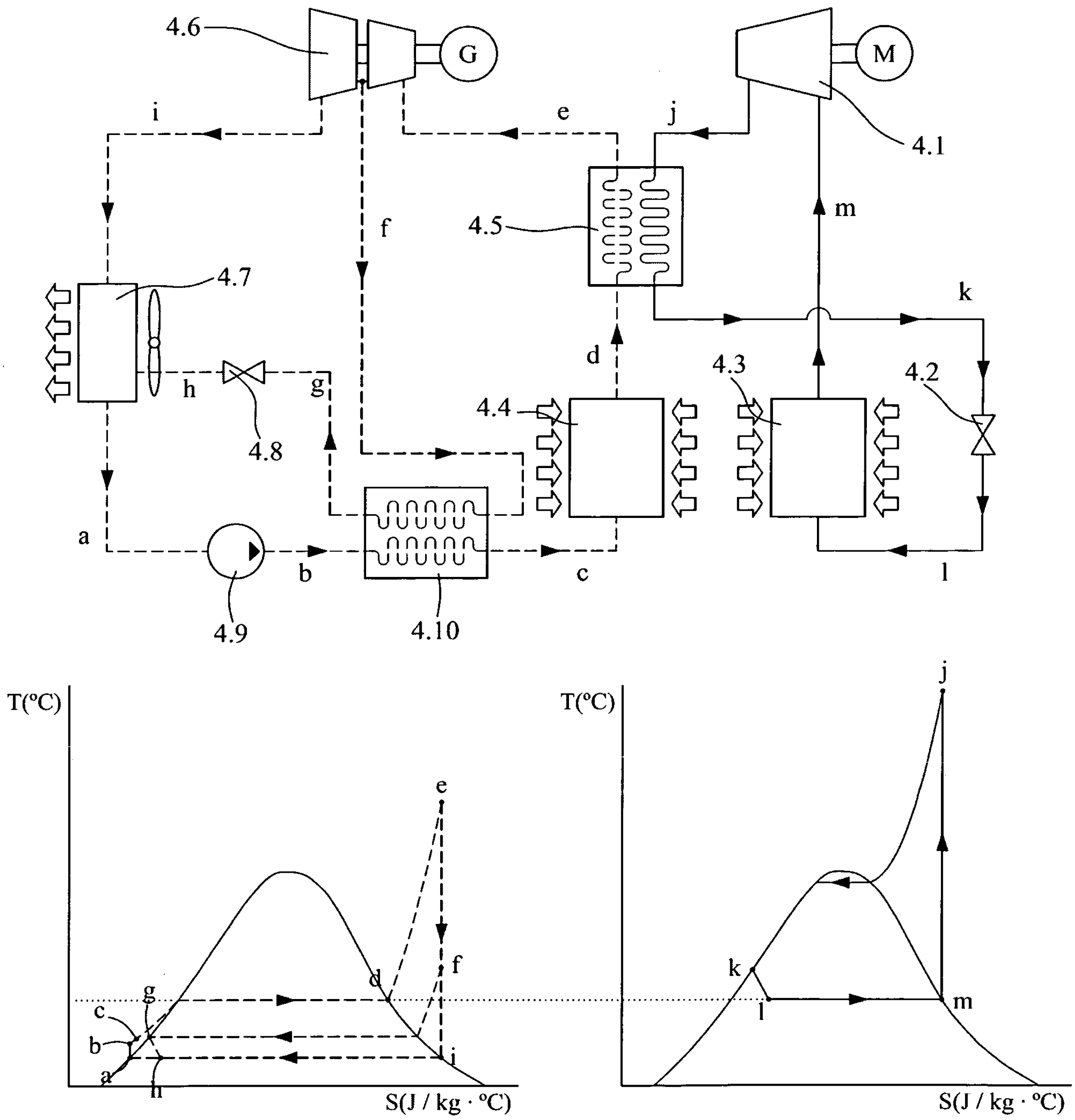
3.9
3.10
a
b
c
d
3.3
k
T(ºC)
f
g
d
e
c
b
h
a
S(J / kg · ºC)
T(ºC)
i
j
k
l
S(J / kg · ºC)

Figure 3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4.2
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4.4
4.8
a
b
c
l
4.9
4.10
T(ºC)
e
d
f
g
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S(J / kg · ºC)
T(ºC)
j
k
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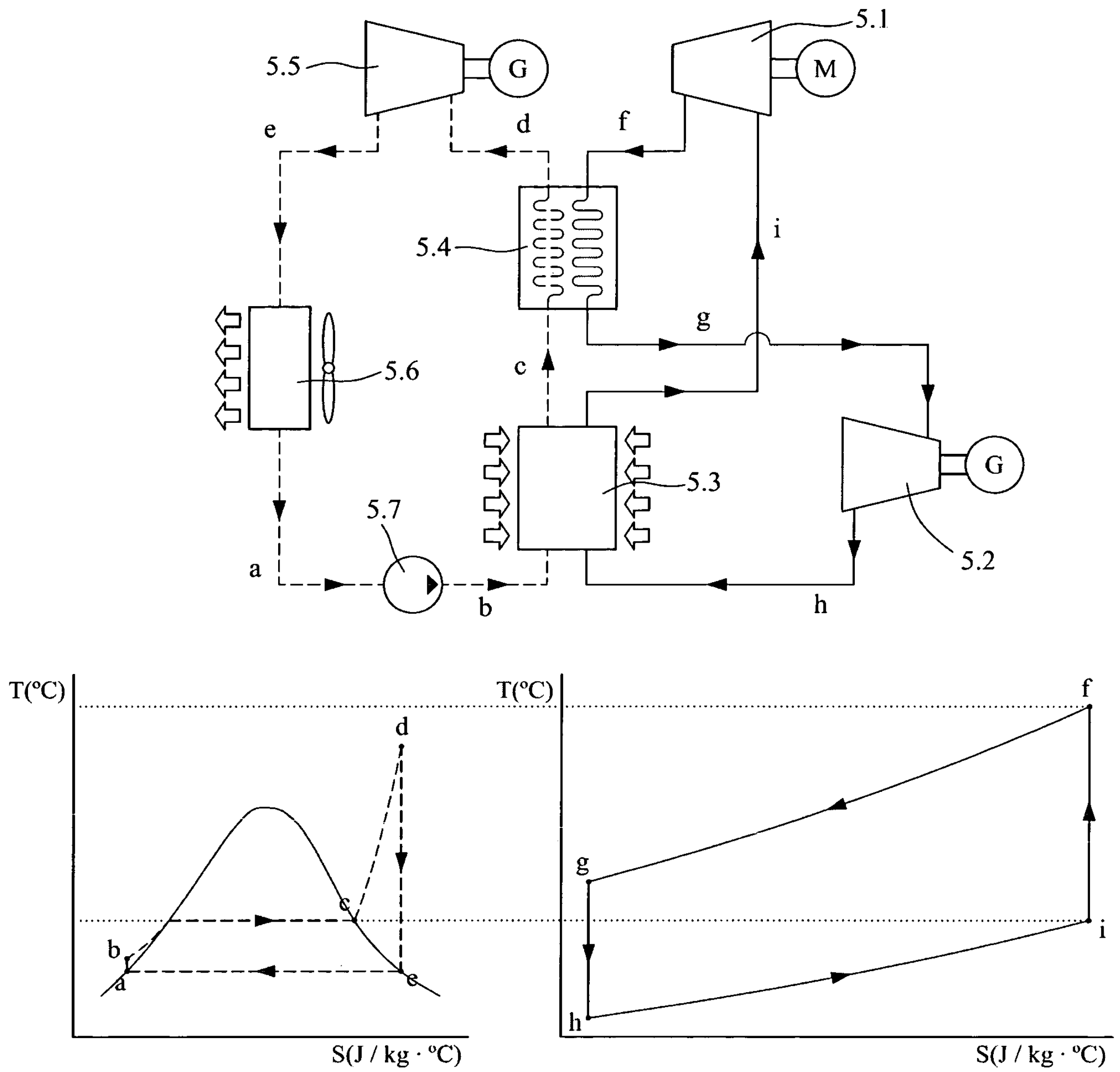
m
S(J / kg · ºC)

Figure 4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b
h
5.2
T(ºC)
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c
b
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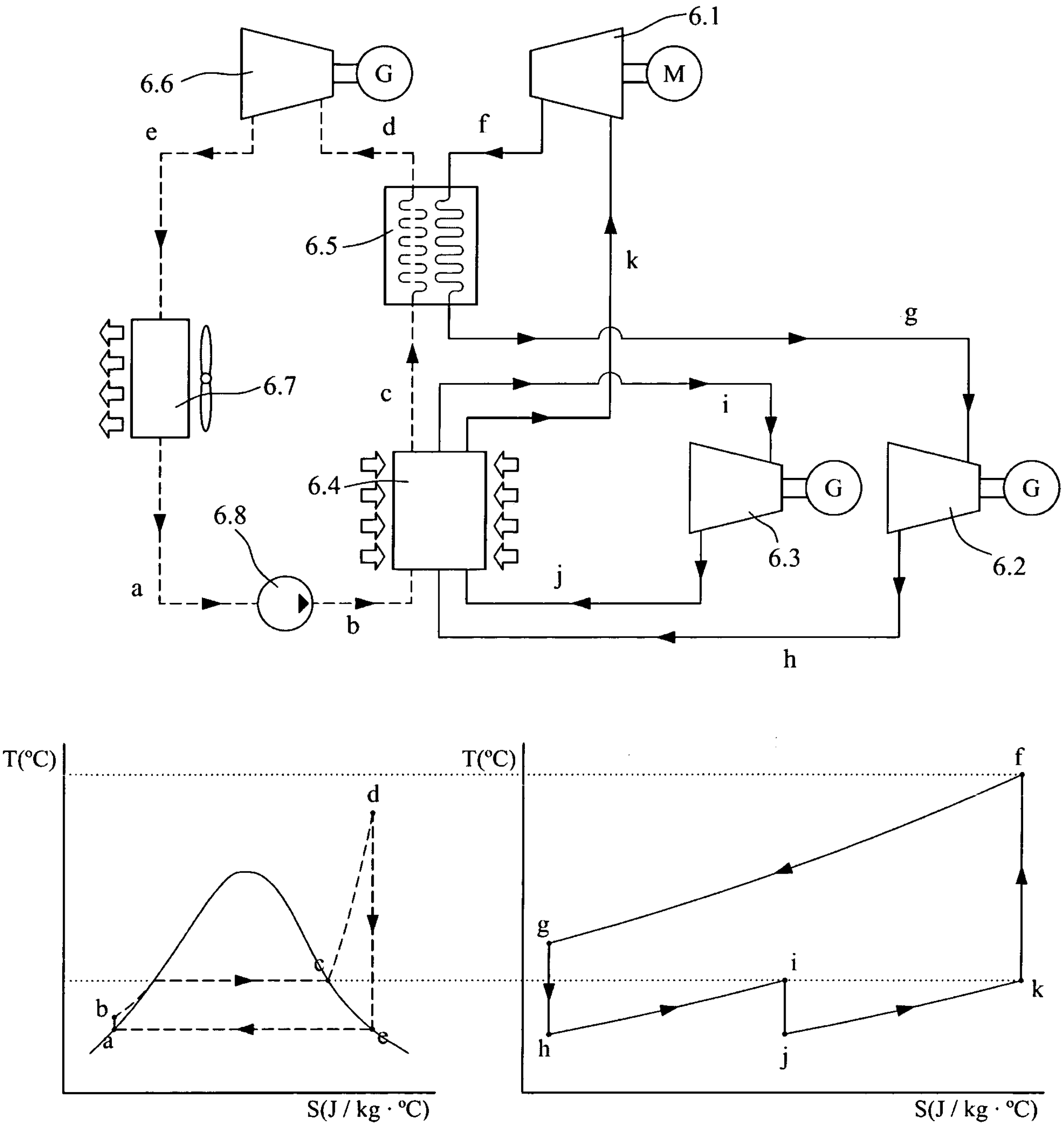
e
S(J / kg · ºC)
T(ºC)
f
g
i
h
S(J / kg · ºC)

Figure 5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6.4
G
G
6.8
6.3
6.2
a
j
b
h
T(ºC)
d
c
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T(ºC)
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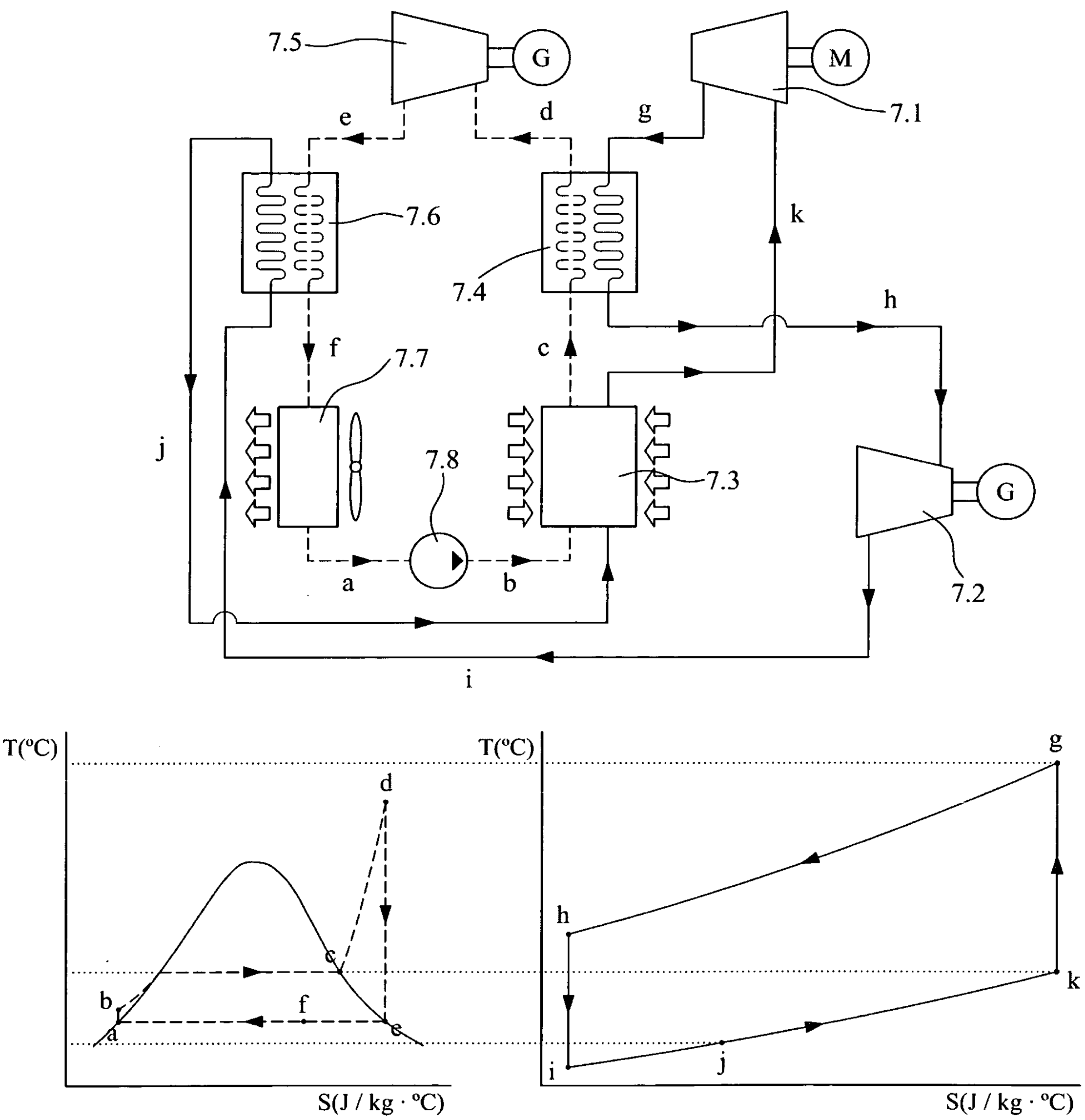
S(J / kg · ºC)

Figure 6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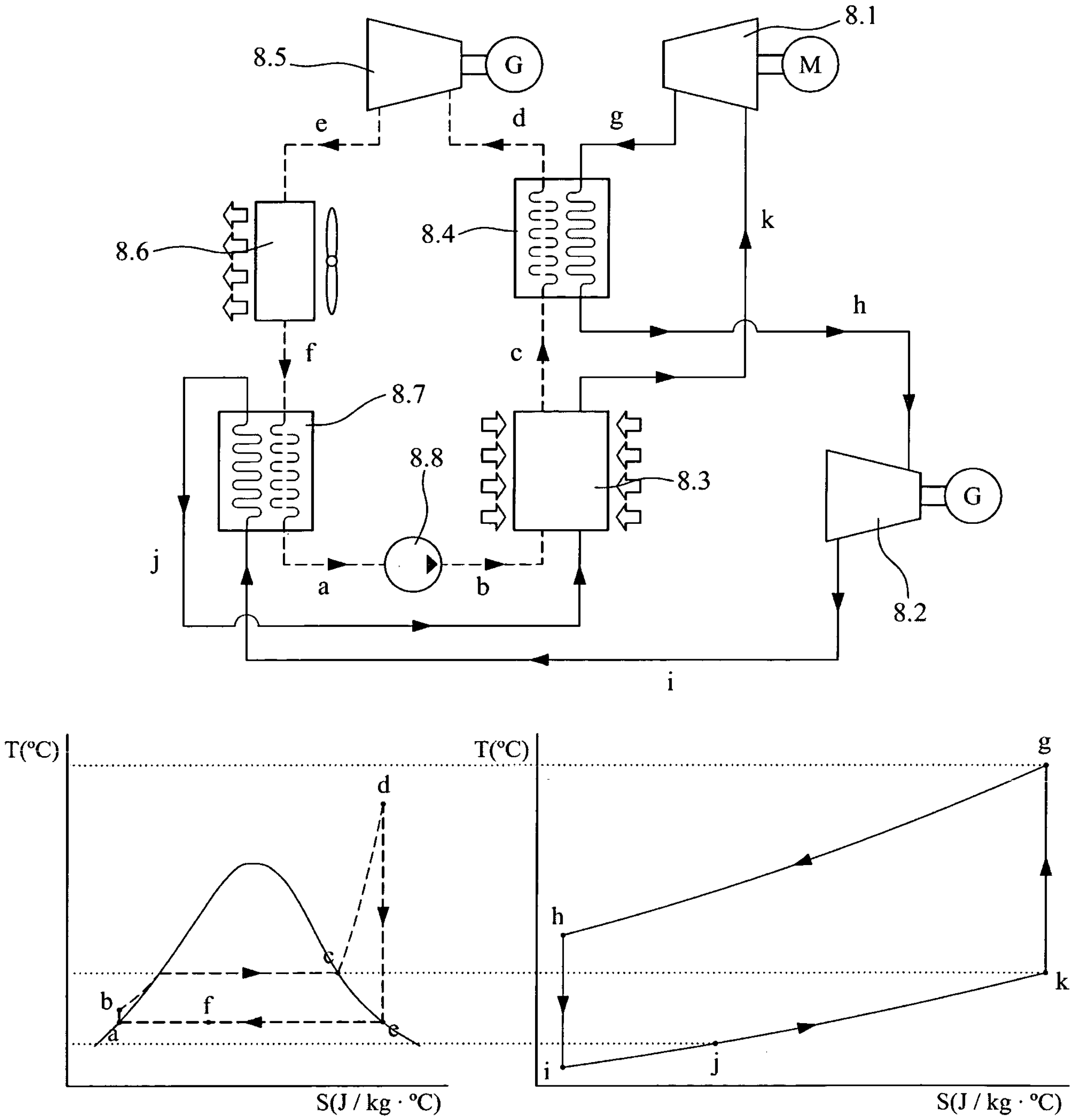
f
c
7.7
j
7.8
7.3
G
7.2
a
b
i
T(ºC)
d
c
b
f
a
e
S(J / kg · ºC)
T(ºC)
g
h
k
i
j
S(J / kg · ºC)

Figure 7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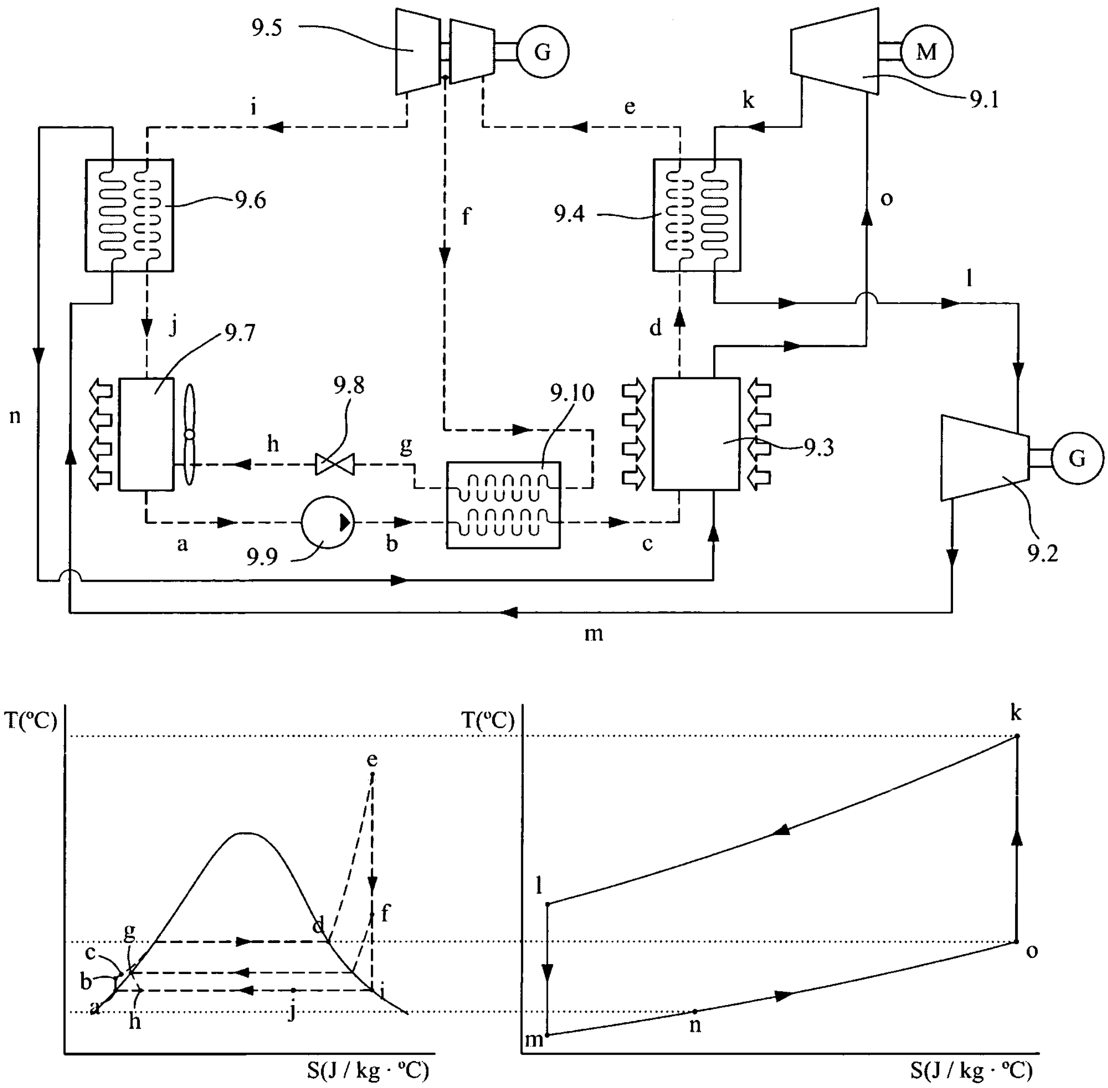
c
8.7
8.8
8.3
G
j
a
b
8.2
i
T(°C)
d
c
b
f
a
e
S(J / kg · °C)
T(°C)
g
h
k
i
j
S(J / kg · °C)

Figure 8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9.8
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h
g
9.3
G
a
9.9
b
c
9.2
m
T(ºC)
S(J / kg · ºC)
e
f
g
d
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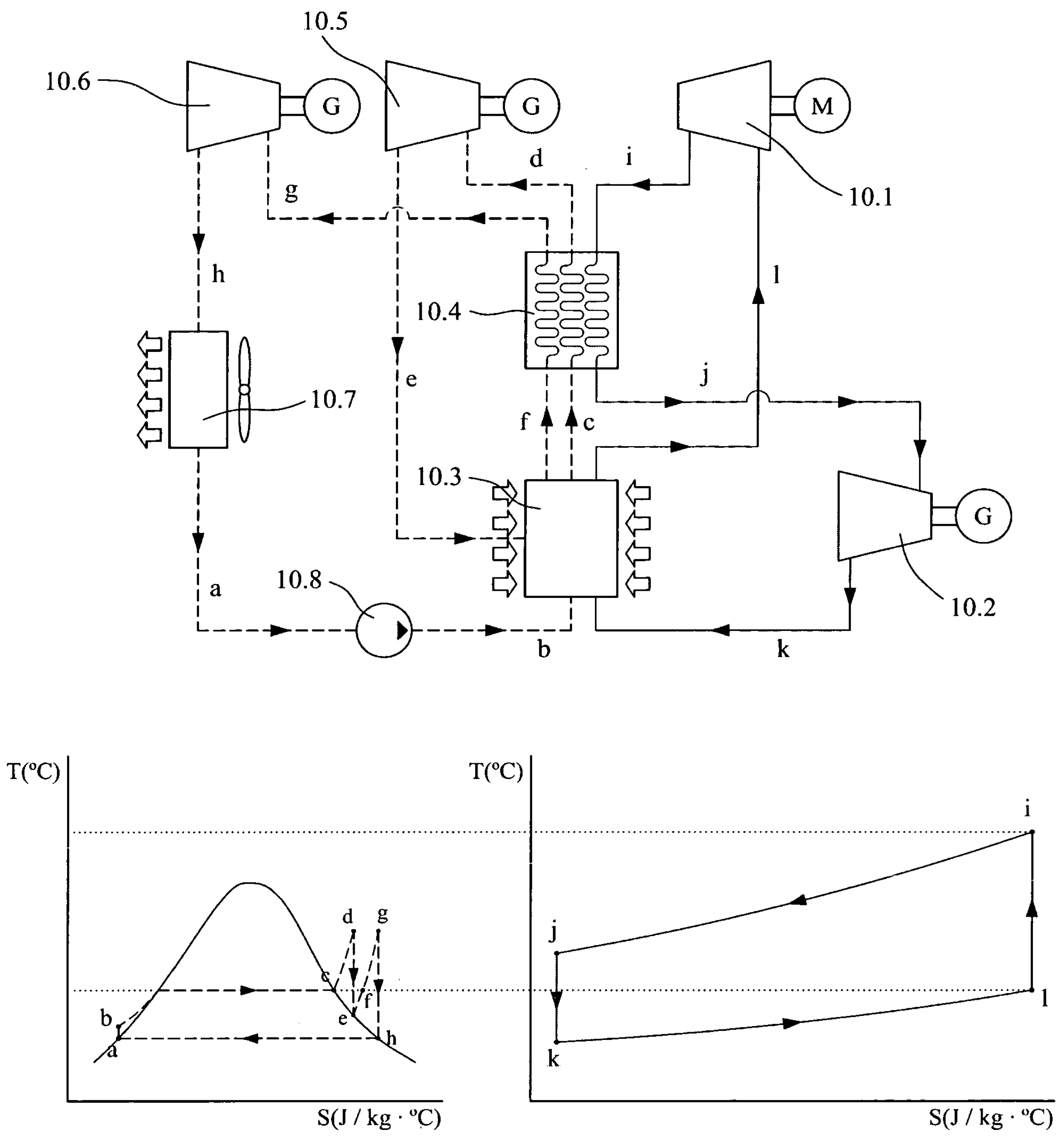
a
h
j
i
T(ºC)
k
l
o
m
n
S(J / kg · ºC)

Figure 9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a
10.8
10.2
b
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T(ºC)
d
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c
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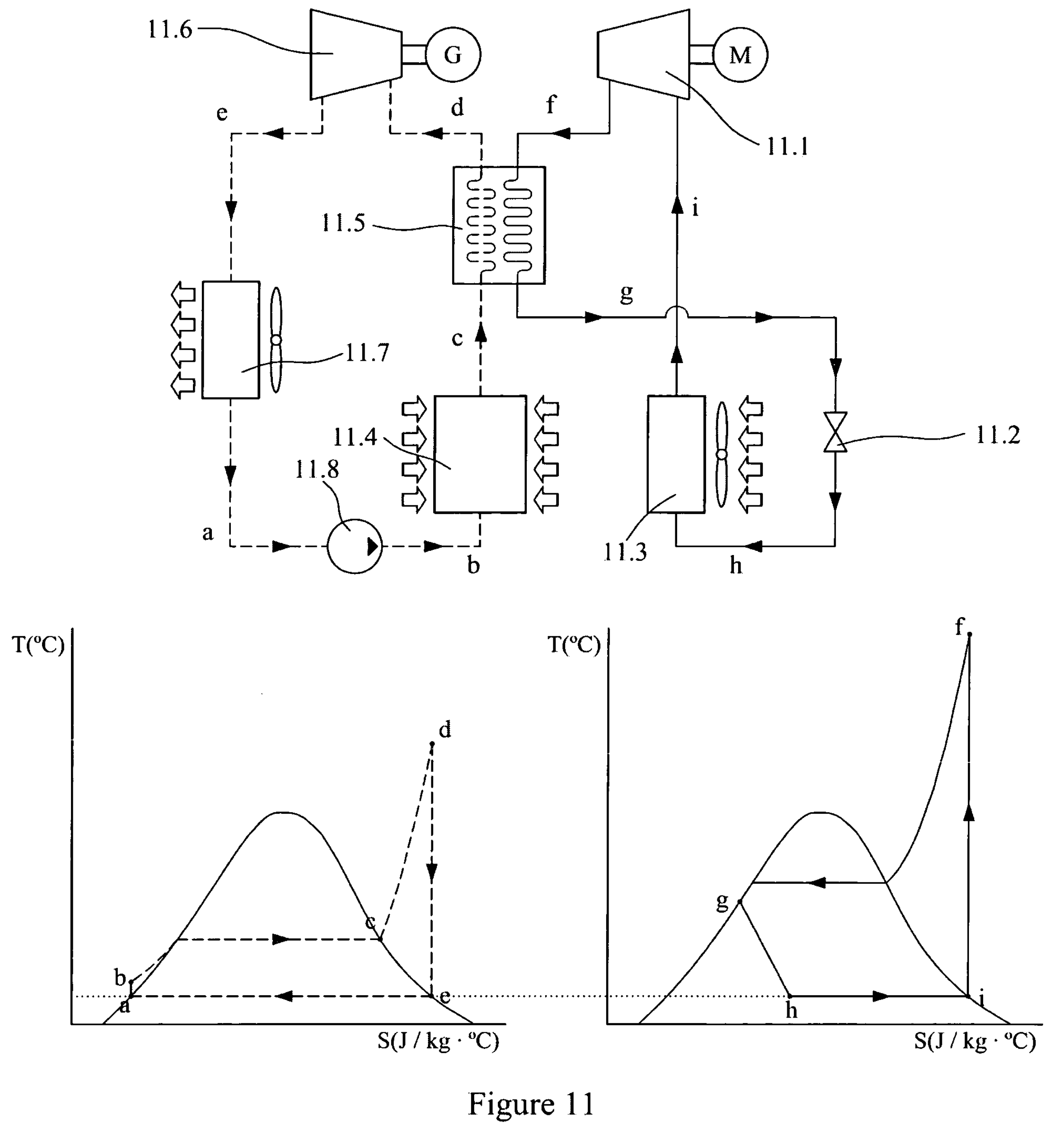
S(J / kg · ºC)
T(ºC)
i
j
l
k
S(J / kg · ºC)

Figure 10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b
11.3
h
T(ºC)
d
c
b
a
e
S(J / kg · ºC)
T(ºC)
f
g
h
i
S(J / kg · ºC)

Figure 11

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EUROPEAN SEARCH REPORT

Application Number
EP 13 00 0615

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X,D	WO 2009/107828 A1 (CALSONIC KANSEI CORP [JP]; KAMIYAMA NAOHISA [JP]; MORI EIICHI [JP]; MA) 3 September 2009 (2009-09-03) * abstract; figure 1 *	1	
A	EP 1 925 786 A1 (SIEMENS AG [DE]) 28 May 2008 (2008-05-28) * paragraphs [0008] - [0018]; figure 1 *	1-11	TECHNICAL FIELDS SEARCHED (IPC)
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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	20 August 2013	Röberg, Andreas

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