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(54) **SYSTEM AND A METHOD OF ENERGY RECOVERY FROM LOW TEMPERATURE SOURCES OF HEAT**

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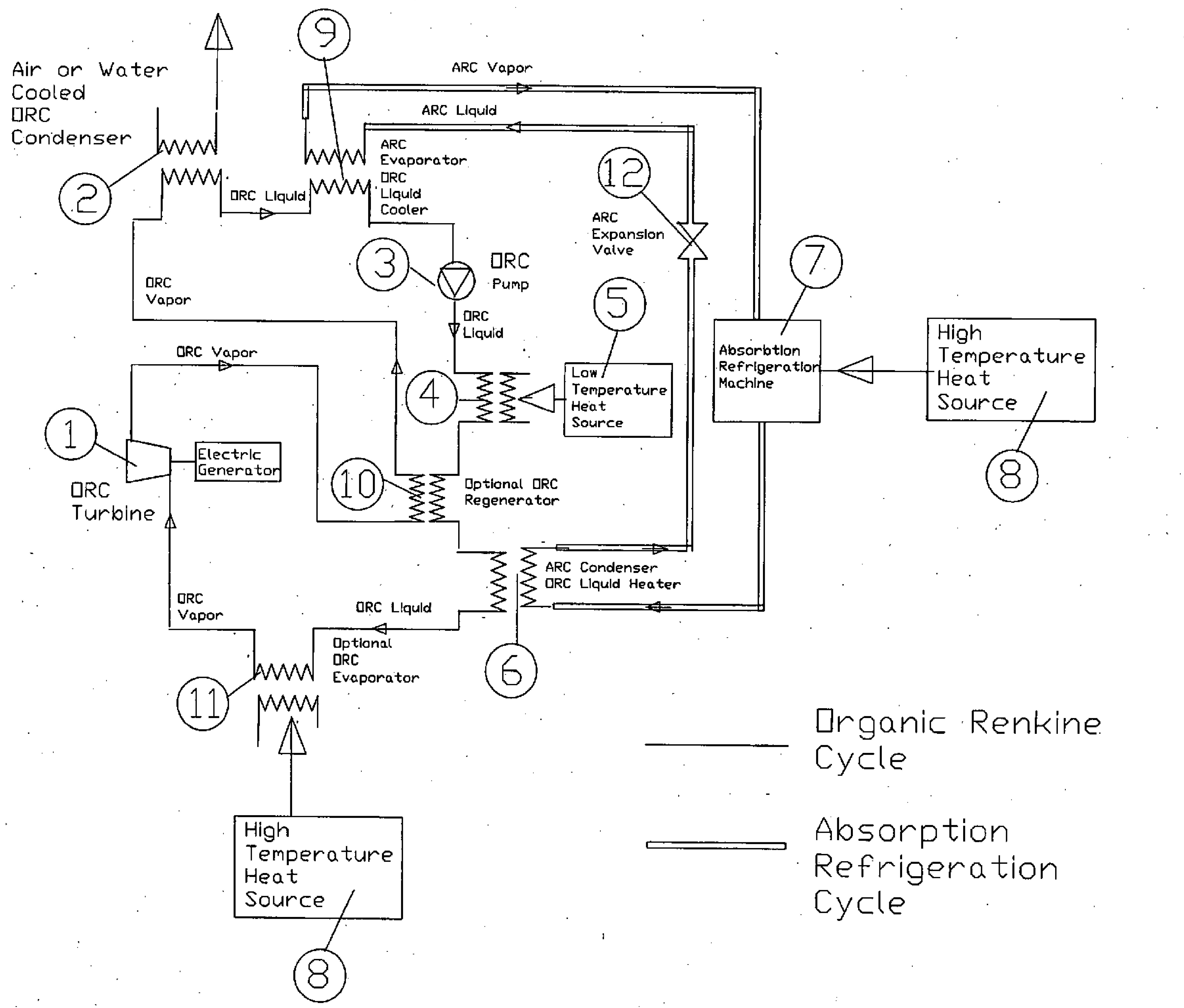
(57) **ABSTRACT**

A system of energy recovery from low temperature sources of heat, comprising components of Organic Renkine Cycle (ORC) including a turbine from which an ORC vapor is withdrawn, a condenser in which the ORC vapor withdrawn from the turbine condenses into an ORC condensate, a pump which circulates the ORC working medium, a heat exchanger which is supplied with a heat carrier from a lower temperature heat source and in which the ORC working liquid, and an ARC Condenser in which the ORC working liquid is heated or evaporates to produce ORC working vapor which is supplied to the turbine; components of an absorption refrigeration cycle (ARC) including an absorption refrigeration machine which receives heat and vaporizes a liquid refrigerant of the ARC to produce an ARC refrigerant vapor which is supplied to the ARC condenser to heat the ORC working liquid; and an additional component increasing a temperature difference between the ORC condensate and the heat carrier from the low temperature heat source.



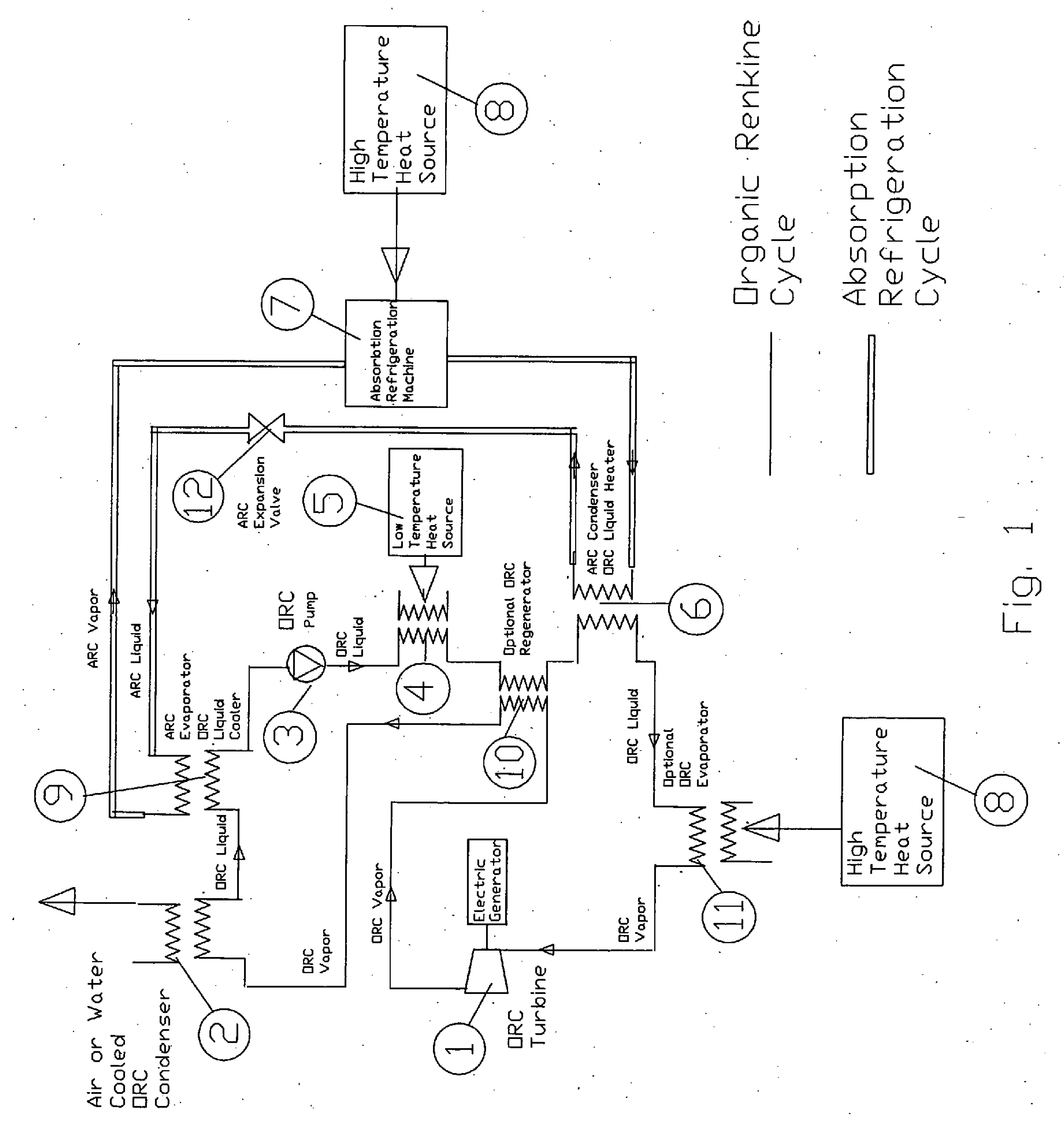

High Temperature Heat Source
Absorbtion Refrigeration Machine
ARC Vapor
ARC Liquid
ARC Expansion Valve
Low Temperature Heat Source
ARC Condenser ORC Liquid Heater
ORC Pump
ORC Liquid
Optional ORC Regenerator
ARC Evaporator ORC Liquid Cooler
ORC Liquid
Optional ORC Evaporator
ORC Vapor
Electric Generator
ORC Turbine
Air or Water Cooled ORC Condenser
Organic Renkine Cycle
Absorption Refrigeration Cycle
1
2
3
4
5
6
7
8
9
10
11
12

Fig. 1

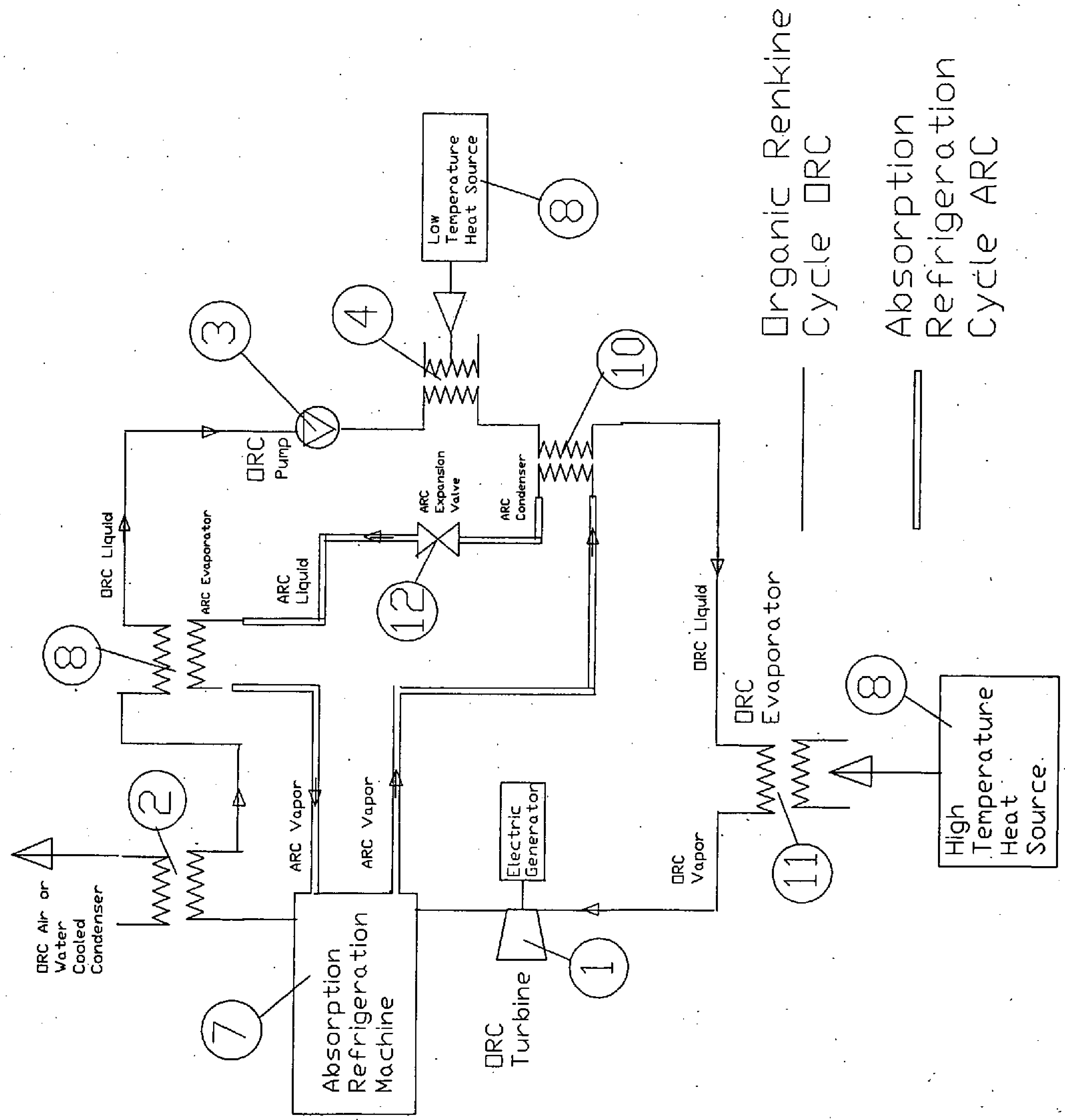

Low Temperature Heat Source
8
4
3
□RC Pump
10
ARC Expansion Valve
ARC Condenser
12
□RC Liquid
ARC Evaporator
ARC Liquid
8
2
□RC Air or Water Cooled Condenser
ARC Vapor
ARC Vapor
Absorption Refrigeration Machine
7
Electric Generator
□RC Turbine
1
□RC Vapor
11
□RC Liquid
□RC Evaporator
8
High Temperature Heat Source
□rganic Renkine Cycle □RC
Absorption Refrigeration Cycle ARC

Fig. 2

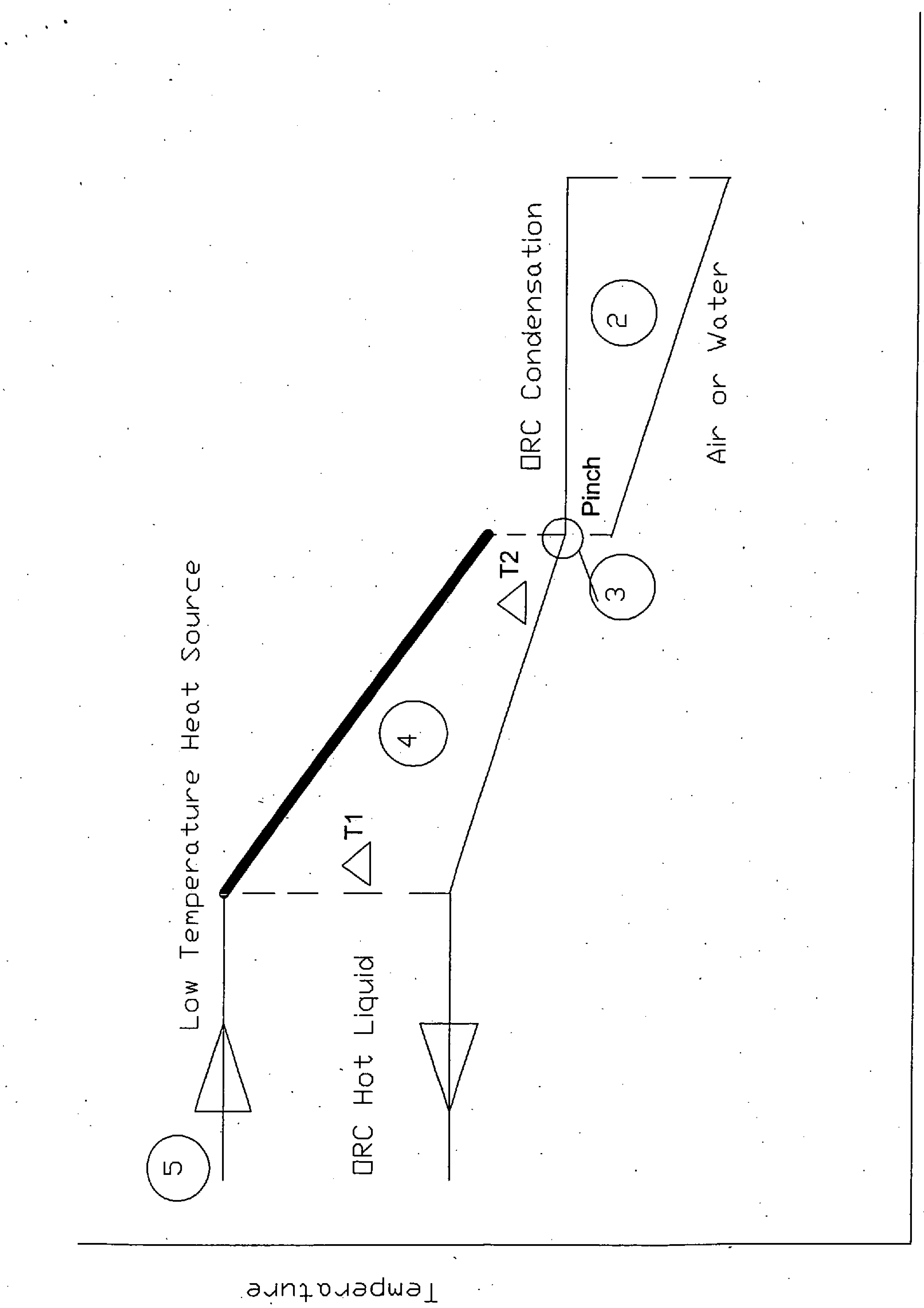

Low Temperature Heat Source
□RC Hot Liquid
□RC Condensation
Air or Water
Pinch
△T1
△T2
1
2
3
4
5
Temperature

Fig. 3

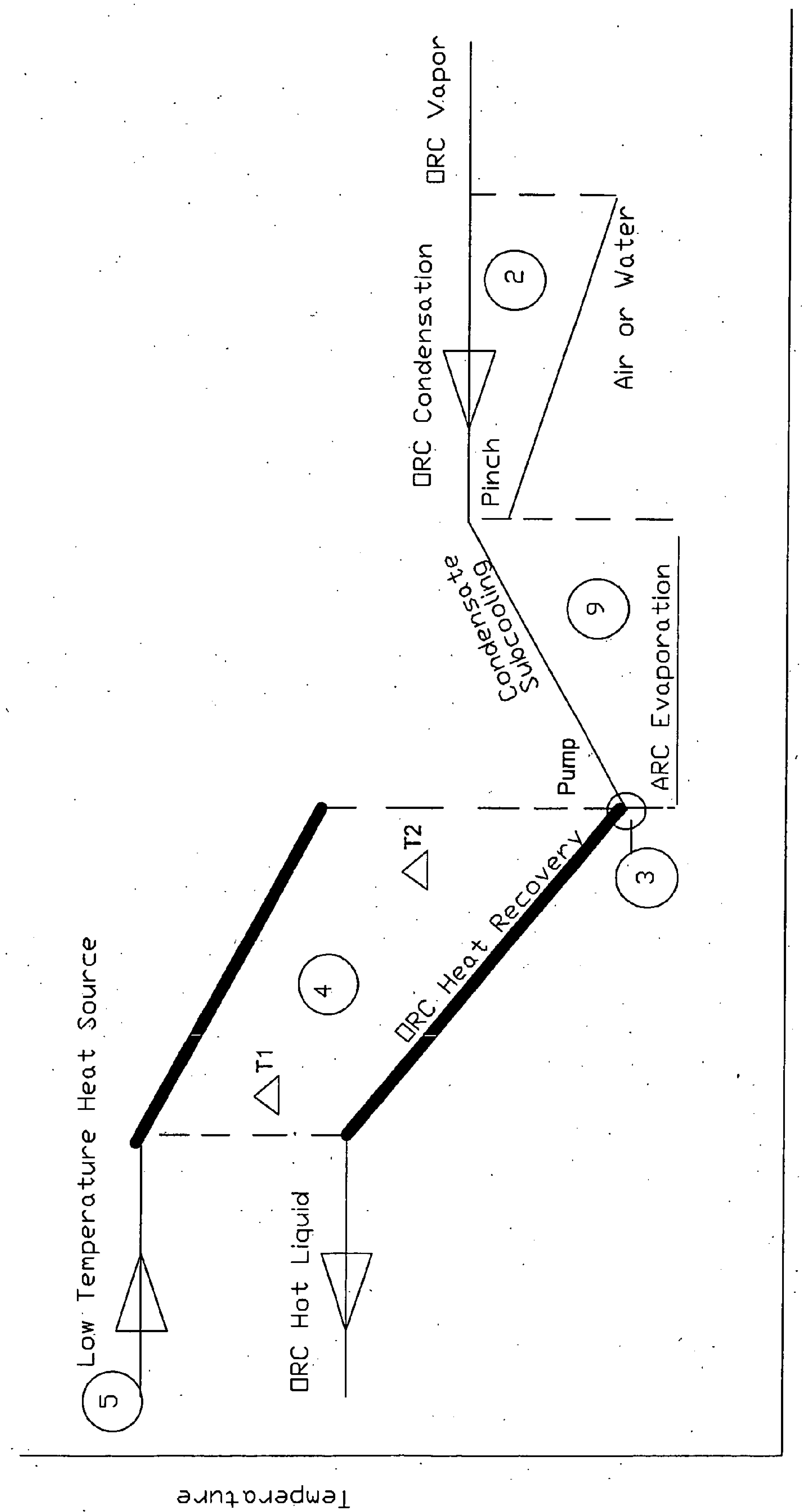

Low Temperature Heat Source
5
ORC Hot Liquid
ΔT1
4
ORC Heat Recovery
ΔT2
3
Pump
Condensate Subcooling
ARC Evaporation
Pinch
ORC Condensation
2
Air or Water
ORC Vapor
Temperature

Fig.4

SYSTEM AND A METHOD OF ENERGY RECOVERY FROM LOW TEMPERATURE SOURCES OF HEAT

BACKGROUND OF THE INVENTION

[0001] The present invention relates to a system and method of energy recovery from low temperature sources of heat.

[0002] Thermodynamic Cycles transferring low temperature heat to electricity are known in the industry.

[0003] In the Kalina Thermodynamic cycle, heat is added to a multi-component mixture that typically contains ammonia and water. This causes the most volatile component to boil off at the lowest temperature. The boiling point changes with the composition, allowing the boiling process to occur at a range of temperatures. This is unlike the Renkine cycle where the boiling temperature is uniquely determined by the pressure. The vapor produced in the boiling process then passes through a turbine which drives the generator, and then to an absorber. The low volatile liquids (which are not boiled in the boiler) are returned to the absorber where they absorb the vapor exhausted from the turbine. The resulting solution is then pumped to a higher pressure and returned to the boiler. The Kalina process is described in U.S. Pat. Nos. 4,346,561 and 4,489,563.

[0004] The Thermodynamic Renkine cycle is commonly known as the steam cycle. In the Renkine cycle water is boiled at high temperature and pressure. The resulting steam is then expanded to a turbine or other device, extracting work to drive an electric generator. The heat is then removed from the steam in a condenser, converting it to water which is then pumped to a higher pressure and returned to the boiler.

[0005] The Organic Renkine Cycle is known as the Renkine Thermodynamic cycle having a working fluid boiled at low temperature and pressure, for example, hydrofluorocarbons, chlorofluorocarbons, ammonia or others. Due to low boiling temperature, ORC is commonly used to recover energy from low temperature heat sources. The amount and the efficiency of ORC systems depend on the temperature difference between a heat source and a working fluid of the cycle. Today the economically justified minimal temperature difference is about 150 deg. F. Due To very high cost of systems energy of many low temperature sources is wasted.

[0006] Absorption Refrigeration Cycle is known in the industry for using waste heat to generate heat and cold. Many concepts of coupling the absorption cycle ARC to the Organic Renkine Cycle (ORC) devein by a low temperature heat source have been evaluated.

[0007] One option of the combined ARC-ORC involves the use of an ARC to increase the temperature of the ORC working liquid fed to the ORC evaporator using external high temperature heat sources. A second alternative proposes the introduction of a vapor absorption chiller to lower the temperature of the working vapor fed to the ORC condenser, similarly to an ORC regenerator, in order to decrease heat losses by an ORC condenser to the ambient. In both cases the purpose is to increase the thermodynamic efficiency of the (ORC).

[0008] It is believe that the known systems and methods can be further improved.

SUMMARY OF THE INVENTION

[0009] Accordingly, it is an object of the present invention to provide a system and a method of energy recovery from low temperature sources of heat, which is a further improvement of the existing systems and methods.

[0010] In keeping with these objects and with others which have become apparent hereinafter, one feature of the present resides, briefly stated, in a system of energy recovery from low temperature sources of heat, comprising:

[0011] components of Organic Renkine Cycle (ORC) including

A low temperature source of heat,

one or more high temperature sources of heat,

a low temperature ORC boiling medium, for instance ammonia, hydrocarbons or others

a turbine from which an ORC vapor is withdrawn,

a condenser in which the ORC working vapor withdrawn from the turbine condenses into a working liquid by iderect heat transfer with ambient air or water,

a pump which pumps the liquid of the ORC working liquid to a higher pressure,

a heat recovery heat exchanger which is supplied by a heat carrier in order to conduct indirect heat transfer between a low temperature heat source and the ORC working liquid.

a heat exchanger which is a ARC condenser supplied by an ARC refrigerant vapor in order to conduct indirect heat transfer between the ORC working liquid and a said ARC condensing refrigerant vapor

an evaporator which in inderect heat transfer with a heat carrier of a high temperature source of heat generates saturated or superheated ORC working vapor further supplied to the turbine

[0012] components of an Absorption Refrigeration Cycle (ARC) including

a refrigerant, for instance ammonia, hydrocarbons or others,

an absorption refrigeration machine which receives heat and vaporizes an ARC refrigerant from mixture of liquids to produce a refrigerant vapor,

an ARC condenser heating in indirected heat transfer ORC working liquid,

an expansion valve reducing pressure of refrigerant liquid passing from ARC condenser to evaporator

and

[0013] an additional heat transfer component,

which may be a countercurrent heat exchnager, increasing in indirect heat transfer a temperature difference between the ORC condensate and the heat carrier from the low temperature heat source.

[0014] Another feature of the present invention resides, briefly stated, in a method of energy recovery from low temperature sources of heat, comprising the steps of:

[0015] in an Organic Renkine Cycle (ORC):

Circulating an ORC working medium, for instance ammonia, hydrofluorocarbons, chlorofluorocarbons or others, which repeatedly changes its thermodinamic state from working liquid to working vapor and from working vapor to working liquid depending on working temperatures and pressure of the said ORC medium.

(a working liquid leaving a condenser called condensate)

[0016] withdrawing an ORC working vapor from a turbine into a condenser condensing the ORC working vapor withdrawn from the turbine into an ORC condenser,

cooling the ORC condensate by indirect heat transfer with ARC evaporating refrigerant,

heating the ORC working liquid or evaporating it by indirect heat trasfer in the ARC condenser in order to generate ORC working vapor which is supplied to the turbine;
optional supplying a heat carrier from a high temperature heat source to evaporate or superheat the said ORC working liquid

[0017] in an absorption refrigeration cycle (ARC):
Circulating an ARC refrigerant, for instance ammonia, hydrofluorocarbons, chlorofluorocarbons or others, which repeatedly changes its thermodinamic state from a refrigerant liquid to a refrigerant vapor and from a refrigerant vapor to a refrigerant liquid depending on working temperatures and pressure of the said ARC medium.
Vaporizing an ARC refrigerant from mixture of liquids in absorption refrigeration machine which receives heat,
in suppling ARC vapor in the ARC condenser in order to heat the ORC working liquid in in inderect heat transfer;
in additional heat transfer component,

[0018] increasing a temperature difference between the condensate of the ORC working medium and the heat carrier from the low temperature heat source.

[0019] When the system is designed and a method is performed in accordance with the present invention, they eliminate the disadvantages of the prior art and provide the corresponding highly advantageous results.

[0020] The novel features which are considered as characteristic for the present invention are set forth in particular in the appended claims. The invention itself, however, both as to its construction and its method of operation, together with additional objects and advantages thereof, will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] FIG. **1** is a view showing a system of energy recovery from low temperature heat sources which implements a method in accordance with the present invention;

[0022] FIG. **2** is a view showing a system of energy recovery from low temperature heat sources which implements a method, in accordance with a further embodiment of the present invention;

[0023] FIG. **3** is a view showing a temperature distribution in a known ORC where a temperature difference T2 between a condensate and a low temperature heat source is relatively low as known in the art; and

[0024] FIG. **4** is a view showing the temperature distribution in the inventive system and method of the ORC and ARC Cycle where a temperature difference T2 between the ORC condensate and a low temperature heat source is significantly increased.

[0025] The temperature difference ΔT**1** depends on the inlet temperature of the heat carrier from the low temperature heat source.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0026] A system of energy recovery from low temperature sources of heat which implements a method in accordance with the present invention, comprises components of an Organic Renkine Cyle and components of Absorption Refrigeration Cycle.

[0027] The components of the Organic Renkine Cycle (ORC) include a turbine **1** from which a working vapor of an ORC working medium is withdrawn,

[0028] a condenser **2** in which the working vapor of the ORC working medium withdrawn from the turbine condenses into a condensate,

[0029] a pump **3** which pumps the condensate of the ORC working medium,

[0030] a heat recovery heat exchanger **4** which is supplied with a heat carrier from a lower temperature heat source **5**,

[0031] an ARC Condenser **6** in which the ORC working liquid is heated,

[0032] and an ORC evaporator **11** in which the ORC working liquid evaporates to produce ORC working vapor which is supplied to the turbine **1**,

[0033] The components of the Absorption Refrigeration Cycle (ARC) include an absorption refrigeration machine **7** which receives heat and vaporizes a n ORC refrigerant produce an ARC refrigerant vapor which is supplied to the ARC condenser **6** to heat the ORC working liquid, and an expansion valve reducing pressure of refrigerant liquid passing from ARC condenser to evaporator

[0034] In accordance with the present invention, an additional component **9** is provided, which increases a temperature difference between the ORC condensate and the heat carrier from the low temperature heat source.
The additional component **9** can be a heat exchanger in which the ORC working liquid cooled by the ARC boiling refrigerant.

[0035] In the embodiment shown in FIG. **1** an additional heat source **8** can supply heat to the absorpotion refrigeration machine **7** to evaporate the ARC liquid refrigerant.

[0036] An optional ORC regenerator **10** can connect the additional component **9** with the ARC condenser **6**, in which the ORC working liquid is further heated by the condensing ARC vapor refrigerant.

[0037] An optional ORC evaporator **11** can be connected with the ARC condenser **6** and the turbine to evaporate the ORC working liquid coming from the said ARC condenser **6**.

[0038] In the embodiment shown in FIG. **2**, the turbine is connected with the absorption refrigeration machine **7** so that the ORC working vapor withdrawn from the turbine vaporizes the ARC refrigerant.

[0039] FIG. **3** shows a temperature difference ΔT**2** of the ORC condensate and the heat carrier from the low temperature heat source in accordance with the prior art, which temperature difference is relatively low.

[0040] FIG. **4** shows a temperature difference ΔT**2** of the ORC condensate and the heat carrier from the low temperature heat source in accordance with the present invention. It can be seen that the temperature difference ΔT**2** in the system and method of the present invention is greater than the temperature difference ΔT**2** in the system and method in accordance with the prior art.

[0041] The temperature difference ΔT**1** depends on the inlet temperature of the heat carrier from the low temperature heat source.

[0042] It will be understood that each of the elements described above, or two or more together, may also find a useful application in other types of methods and constructions differing from the types described above.

[0043] While the invention has been illustrated and described as embodied in a system and method of energy recovery from low temperatire sources of heat, it is not intended to be limited to the details shown, since various modifications and structural changes may be made without departing in any way from the spirit of the present invention.

[0044] Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can, by applying current knowledge, readily adapt it for various applications without omitting features that, from the standpoint of prior art, fairly constitute essential characteristics of the generic or specific aspects of this invention.

[0045] What is claimed as new and desired to be protected by Letters Patent is set forth in the appended claims.

What is claimed is:

1. A system of energy recovery from low temperature sources of heat, including components of Organic Renkine Cycle (ORC) comprising:
 ORC working medium,
 a turbine from which a vapor of an ORC working medium is withdrawn,
 a condenser in which the ORC vapor withdrawn from the turbine condenses into a condensate, which is also an ORC working liquid,
 a pump which circulates the working liquid,
 a heat recovery heat exchanger which is supplied with a heat carrier from a low temperature heat source and in which the ORC working liquid is heated,
 an a ARC condenser in which the ORC working liquid is heated or evaporates to produce the ORC working vapor which is supplied to the turbine,
 an additional optional ORC evaporator to generate an ORC working vapor which is supplied with a heat carrier from a high temperature heat source,
 and
 including components of Absorption Refrigeration Cycle (ARC) comprising
 ARC refrigerant,
 an absorption refrigeration machine which receives heat and vaporizes an ARC refrigerant to produce an ARC refrigerant
 an ARC condenser to heat the ORC working liquid,
 an expansion valve provides an adiabatic expansion of the ARC refrigerant liquid passing from an ARC refrigerant condenser to an ARC refrigerant evaporator
 and
 an additional component, which may be a heat exchanager, increasing a temperature difference between the ORC condensate and the heat carrier from the low temperature heat source.

2. A system of energy recovery as defined in claim **1**; further comprising an additional heat source which supplies heat to the absorpotion refrigeration machine to vaporize ARC refrigerant.

3. A system of energy recovery as defined in claim **1**; further comprising a pump circulating an ORC working medium

4. A system of energy recovery as defined in claim **1**; further comprising an ORC regenerator connecting said additional component with said ARC condenser, in which the ORC working liquid is further heated by the condensing ARC vapor.

5. A system of energy recovery as defined in claim **1**; further comprising an ORC evaporator which is connected with said ARC condenser and said turbine to evaporate the ORC working liquid coming from said ARC condenser.

6. A system of energy recovery as defined in claim **1**, wherein said turbine is connected with said absorption refrigeration machine so that the working vapor of the ORC working medium withdrawn from said turbine heatS and vaporizes the the ARC refrigerant in the absorption refrigeration machine.

7. A method of energy recovery from low temperarture sources of heat, comprising the step of:
 in an Organic Renkine Cycle (ORC) withdrawing from a turbine an ORC working vapor into a condenser condensing the ORC working vapor withdrawn from the turbine into a condensate which is ORC working liquid, pumping the ORC working medium, in a heat recovery heat exchanger supplying a heat carrier from a lower temperature heat source and heating the ORC working liquid, and in an ARC Condenser heating the ORC working liquid or evaporating it to produce ORC working vapor which is supplied to the turbine;
 in an absorption refrigeration cycle (ARC) in an absorption refrigeration machine receiving heat and vaporizing an ARC refrigerant to produce an ARC refrigerant vapor which is supplied to the ARC condenser heating the ORC working liquid and
 increasing a temperature difference between the ORC condensate and the heat carrier from the low temperature heat source in an additional component.

8. A method of energy recovery as defined in claim **1**; further comprising supplying heat from an additional heat source to the absorption refrigeration machine to vaporize the ARC refrigerant.

9. A method of energy recovery as defined in claim **1**; further comprising in an ORC regenerator connecting said additional component with said ARC condenser which is further heating the ORC working liquid by the ARC condesing vapor.

10. A method of energy recovery as defined in claim **1**; further comprising in an evaporator which is connected with said ARC condenser and said turbine, evaporating the ORC working liquid coming from said ARC condenser.

11. A method of energy recovery as defined in claim **1**, further comprising connecting said turbine with said absorption refrigeration machine so that the working vapor of the ORC working medium withdrawn from said turbine heats and vaporizes the ARC refrigerant in the absorption refrigeration machine.

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