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(72) Inventor: **Pal, Madan**
Portsmouth, PO1 3LS (GB)

(74) Representative: **BAE SYSTEMS plc**
Group IP Department
Warwick House
P.O. Box 87
Farnborough Aerospace Centre
Farnborough Hampshire GU14 6YU (GB)

(71) Applicant: **BAE SYSTEMS plc**
London SW1Y 5AD (GB)

(54) **MODULATING AND CONDITIONING WORKING FLUIDS**

(57) In some examples, an apparatus comprises a first working fluid circuit comprising a first working fluid, a heat exchanger fluidly coupled to and in thermal communication with the first working fluid circuit, the heat exchanger to transfer thermal energy from a heat source stream to the first working fluid within the first working fluid circuit, a recuperator fluidly coupled to and in thermal communication with the first working fluid circuit and disposed downstream of the heat exchanger, a first condenser fluidly coupled to and in thermal communication

with the first working fluid circuit and disposed downstream of the recuperator, a second working fluid circuit comprising a second working fluid, the second working fluid circuit coupled to and in thermal communication with the first condenser, a second condenser fluidly coupled to and in thermal communication with the second working fluid circuit and disposed downstream of the first condenser, and a third working fluid circuit comprising a third working fluid, the third working fluid circuit coupled to and in thermal communication with the second condenser.

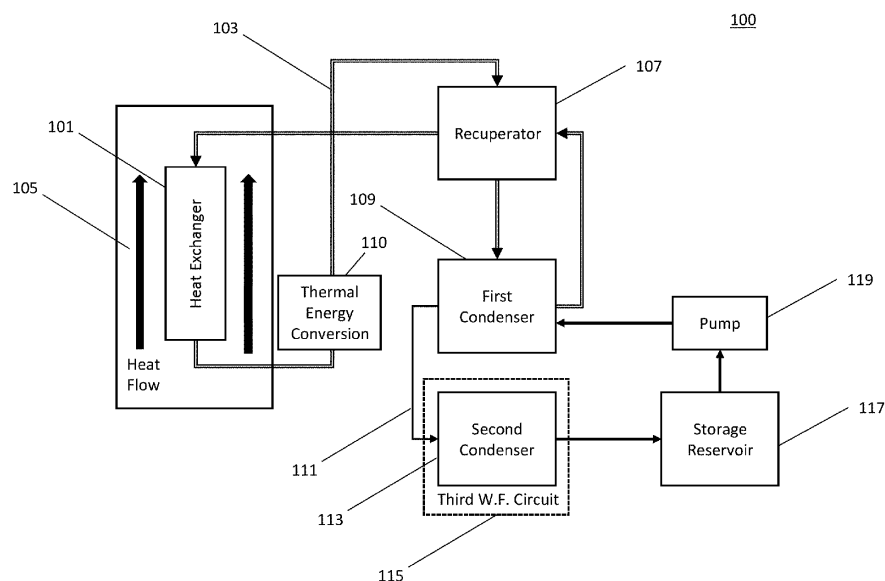


Figure 1

Description

FIELD

[0001] The present invention relates to modulation and conditioning of working fluids.

BACKGROUND

[0002] Heat is often created as a byproduct of industrial or mechanical processes and is discharged when, e.g., heated liquids, solids, and/or gasses are exhausted into the environment or when heat is removed from the medium in question. For example, heat removal can be performed to avoid exceeding safe and efficient operating temperatures in a process or system or may be inherent as exhaust in open cycles. Exceeding safe and efficient operating temperatures can cause damage or reduced efficiency in the process or system concerned. Furthermore, useful thermal energy is generally lost when this heat is not recovered or recycled during such processes.

[0003] In order to recover heat that would otherwise be lost to the external environment, heat exchanging devices can be used to recover heat and recycle thermal energy back into the process. Heat can also be converted into mechanical energy that can be used to generate electrical energy.

[0004] There are several factors that can limit waste heat recovery. For example, the exhaust or heat source stream from which heat is to be extracted may be reduced to low-grade (e.g., low temperature) heat, from which economical energy extraction is difficult, or the heat may otherwise be difficult to recover. Another limiting factor arises in the form of the efficiency of the material that is used to transfer thermal energy from the heat source stream for the purposes of, e.g., heat extraction.

SUMMARY

[0005] According to a first aspect of the present disclosure, there is provided an apparatus, comprising a first working fluid circuit comprising a first working fluid, a heat exchanger fluidly coupled to and in thermal communication with the first working fluid circuit, the heat exchanger to transfer thermal energy from a heat source stream to the first working fluid within the first working fluid circuit, a recuperator fluidly coupled to and in thermal communication with the first working fluid circuit and disposed downstream of the heat exchanger, a first condenser fluidly coupled to and in thermal communication with the first working fluid circuit and disposed downstream of the recuperator, a second working fluid circuit comprising a second working fluid, the second working fluid circuit coupled to and in thermal communication with the first condenser, a second condenser fluidly coupled to and in thermal communication with the second working fluid circuit and disposed downstream of the first condenser, and a third working fluid circuit comprising a third working

fluid, the third working fluid circuit coupled to and in thermal communication with the second condenser. In some examples, a condenser may be replaced by a heat exchanger. Accordingly, while there is heat exchange as part of an operation, this heat exchanged may or may not accompany a condensing stage.

[0006] Such an apparatus can significantly improve overall efficiency of a thermomechanical cycle while reducing the size and weight of a thermomechanical waste heat recovery system. Working fluids used in such a thermomechanical waste heat recovery system can be optimally conditioned, thereby significantly improving the overall cycle efficiency of the system.

[0007] In an implementation of the first aspect, an expansion device can be fluidly coupled to and in thermal communication with the first working fluid circuit and disposed downstream of the heat exchanger and upstream of the recuperator. A compression device can be fluidly coupled to and in thermal communication with the first working fluid circuit and disposed downstream of the expansion device and upstream of the recuperator. A pump can be fluidly coupled to the second working fluid. The pump can circulate the second working fluid within the second working fluid circuit. In an example, the pump can be disposed upstream of the first condenser and downstream of the second condenser. A storage vessel can be fluidly coupled to the second working fluid circuit to store the second working fluid for the second working fluid circuit. The expansion device can generate mechanical energy from expansion of the first working fluid therein, and a generator can be coupled to the expansion device to convert the mechanical energy to electrical energy. The expansion device can generate mechanical energy from expansion of the first working fluid therein, and the compression device can be coupled to the expansion device whereby to receive mechanical energy therefrom. The compression device can compress the first working fluid for the recuperator. At least one of the heat exchanger, recuperator, first condenser and second condenser can comprise a thermoelectric generator fluidly coupled thereto and in thermal communication therewith. A controller can be provided to control a mode of operation of the or each thermoelectric generator in response to a condition signal generated by a sensor configured to generate a measure representing a condition of the first working fluid. The sensor can be provided at one of an inlet and outlet of at least one of the heat exchanger, recuperator, first condenser and second condenser. The or each thermoelectric generator can heat and/or cool at least one of the first, second and third working fluids.

[0008] In an example, a second heat exchanger fluidly coupled to and in thermal communication with the first working fluid circuit can be provided. The second heat exchanger can transfer thermal energy from the heat source stream to the first working fluid within the first working fluid circuit. A second expansion device can be provided fluidly coupled to and in thermal communication with the first working fluid circuit and disposed down-

stream of the heat exchanger and upstream of the second heat exchanger. Any one of the first working fluid, the second working fluid and the third working fluid can be selected from any one or more of air, water, a mixture of water and glycol, a mixture of: water, glycol, metallic nano-oxides, butylbenzene, propylbenzene, ethylbenzene, toluene, octamethyl cyclotetrasiloxane (OMTS), butane, isobutene, n-butane, n-hexane, RC-318, R-227ea, R-113, iso-pentane, neo-pentane, R-245fa, R-236ea, C5F12, R236fa, helium, carbon dioxide, supercritical carbon dioxide, other refrigerants and noble gases, or a mixture thereof.

[0009] According to a second aspect of the present disclosure, there is provided a method for modulating and conditioning a working fluid, the method comprising heating a first mass flow of a first working fluid in a heat exchanger fluidly coupled to and in thermal communication with a first working fluid circuit and a heat source stream, wherein the heat exchanger is configured to transfer thermal energy from the heat source stream to the first mass flow of the first working fluid within the first working fluid circuit, transferring, via a recuperator, heat from the first mass flow downstream of the heat exchanger and upstream of a first condenser to the first mass flow downstream of the first condenser and upstream of the heat exchanger, condensing the first mass flow of the first working fluid in a first condenser fluidly coupled to the first working fluid circuit, condensing a second mass flow of a second working fluid of a second working fluid circuit fluidly coupled to and in thermal communication with the first condenser, the second mass flow condensed using a second condenser fluidly coupled to and in thermal communication with the second working fluid circuit and disposed downstream of the first condenser, conditioning, using a third mass flow of a third working fluid within a third working fluid circuit coupled to and in thermal communication with the second condenser, the second mass flow of the second working fluid.

[0010] In an implementation of the second aspect, the method can further comprise at least one of heating and cooling any one or more of the first working fluid, the second working fluid and the third working fluid using one or more thermoelectric generators fluidly coupled to and in thermal communication with the first working fluid circuit and/or the second working fluid circuit and/or the third working fluid circuit. The method can further comprise determining a condition of the first working fluid and/or the second working fluid and/or the third working fluid from respective condition signals generated by one or more sensors provided at at least one of an inlet and outlet of at least one of the heat exchanger, recuperator, first condenser and second condenser, and using the condition signals, generating at least one control signal. The method can further comprise regulating a respective mode of operation of the or each thermoelectric generator using a control signal. The method can further comprise generating the at least one control signal using a controller operatively coupled to the one or more sensors.

The method can further comprise generating, using the one or more thermoelectric generators, electrical energy by way of the Seebeck effect. The method can further comprise selecting a respective mode of operation of the or each thermoelectric generator from one of heating and cooling, whereby to regulate the temperature of the first working fluid and/or the second working fluid and/or the third working fluid, and generation of electrical energy.

[0011] According to a third aspect of the present disclosure, there is provided a non-transitory machine-readable storage medium encoded with instructions for modulating and conditioning a working fluid, the instructions executable by a processor of a controller of an apparatus as provided in accordance with the first aspect, whereby to cause the controller to regulate a mode of operation of at least one thermoelectric generator using a control signal received from a sensor, the control signal representing a condition of the first working fluid and/or the second working fluid and/or the third working fluid.

[0012] In an implementation of the third aspect, the non-transitory machine-readable storage medium can be further encoded with instructions to cause the controller to heat or cool respective ones of the first working fluid and/or the second working fluid and/or the third working fluid, and/or generate electrical energy using the at least one thermoelectric generator. The non-transitory machine-readable storage medium can be further encoded with instructions to cause the controller to generate the control signal on the basis of one or more condition signals received from one or more sensors provided at at least one of an inlet and outlet of at least one of the heat exchanger, recuperator, first condenser and second condenser.

BRIEF DESCRIPTION OF THE FIGURES

[0013] Embodiments of the invention will now be described by way of example only with reference to the figures, in which:

Figure 1 is a schematic representation of an apparatus according to an example;

Figure 2 is a schematic representation of an apparatus according to an example;

Figure 3 is a schematic representation of an apparatus according to an example;

Figure 4 is a schematic representation of an apparatus according to an example;

Figure 5 is a schematic representation of a thermoelectric generator according to an example; and

Figure 6 is a schematic representation of a machine according to an example.

DETAILED DESCRIPTION

[0014] Example embodiments are described below in sufficient detail to enable those of ordinary skill in the art to embody and implement the systems and processes herein described. It is important to understand that embodiments can be provided in many alternate forms and should not be construed as limited to the examples set forth herein.

[0015] Accordingly, while embodiments can be modified in various ways and take on various alternative forms, specific embodiments thereof are shown in the drawings and described in detail below as examples. There is no intent to limit to the particular forms disclosed. On the contrary, all modifications, equivalents, and alternatives falling within the scope of the appended claims should be included. Elements of the example embodiments are consistently denoted by the same reference numerals throughout the drawings and detailed description where appropriate.

[0016] The terminology used herein to describe embodiments is not intended to limit the scope. The articles "a," "an," and "the" are singular in that they have a single referent, however the use of the singular form in the present document should not preclude the presence of more than one referent. In other words, elements referred to in the singular can number one or more, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises," "comprising," "includes," and/or "including," when used herein, specify the presence of stated features, items, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, items, steps, operations, elements, components, and/or groups thereof.

[0017] Unless otherwise defined, all terms (including technical and scientific terms) used herein are to be interpreted as is customary in the art. It will be further understood that terms in common usage should also be interpreted as is customary in the relevant art and not in an idealized or overly formal sense unless expressly so defined herein.

[0018] In a thermomechanical waste heat recovery system, a working fluid is used to transfer thermal energy from a heat source stream. The working fluid can be a gas, a liquid, a mixture of both, or a supercritical fluid for example, which is typically maintained in a closed loop system forming a working fluid circuit. The working fluid circuit, comprising the working fluid, can be fluidly coupled to and in thermal communication with the heat source stream, such as, e.g., an exhaust stream of an engine or the like by way of a heat exchanger configured to transfer thermal energy from the heat source stream to the working fluid within the working fluid circuit. That is, the working fluid circuit can be in fluid communication with, e.g., a heat exchanger with a thermal communication or coupling between the two to enable heat from the heat source stream to be effectively removed therefrom.

Removal of thermal energy enables, for example, safe and efficient operating temperatures to be maintained and/or generation of mechanical energy from a proportion of the heat that has been removed. Thermal energy that has been removed from a system can also be used to generate, e.g., electrical energy by way of thermoelectric generators or used for process heating.

[0019] An optimally conditioned working fluid can significantly improve the overall cycle efficiency of the thermomechanical waste heat recovery system in question. For example, the temperature and enthalpy of a working fluid can be optimised in order to achieve maximum work output from, e.g., an expansion device through which a relatively high pressure working fluid is expanded to produce work that can be used to drive a compressor or generator. Generally, in the context of working fluids, deterioration of the working fluid enthalpy can lead to a consequential deterioration of the work output from an expansion device for example. To minimise under-expansion and over-expansion losses and to optimise the performance of an expansion device, the operating condition (enthalpy and temperature) of a working fluid should therefore ideally match the optimum operational conditions of the expansion device.

[0020] According to an example, there is provided an apparatus in which modulation and conditioning of one or more working fluids can be performed in order to optimise the enthalpy and temperature of the working fluids, thereby enabling an efficient transfer of thermal energy from a heat source stream to a working fluid.

[0021] Figure 1 is a schematic representation of an apparatus according to an example. In the example of figure 1, a heat exchanger 101 is fluidly coupled to and in thermal communication with a first working fluid circuit 103 (denoted by way of double lined arrows) comprising a first working fluid. The first working fluid circuit forms a closed loop circuit in which the first working fluid circulates in the direction depicted by the arrows. An upstream direction is a direction that is opposite to that of the mass fluid flow (i.e., in terms of the first working fluid circuit, a direction that is opposite to the direction of the arrows) whilst a downstream direction is a direction that is the same as that of the mass fluid flow. According, at a given point in a working fluid circuit, a first device or component may be described as being upstream or downstream of a second device or component. That is, the first component may be disposed before or after the second component considering the direction of flow of the working fluid in the working fluid circuit. This does not preclude the presence of additional components logically disposed between the first and second components. That is, in the sense of a fluid flow, a first component may be disposed upstream of a second component irrespective of the presence or absence of other components disposed therebetween. The first working fluid circuit can comprise a storage apparatus/buffer for a working fluid and a pump in order to circulate the working fluid within the first working fluid circuit and/or regulate the pressure

of the first working fluid.

[0022] With reference to figure 1, the heat exchanger 101 is configured to transfer thermal energy from a heat source stream 105 to the first working fluid within the first working fluid circuit 103. The heat source stream 105 can be, e.g., an exhaust stream of a mobile platform (such as a land-, air- or water-based vehicular platform for example) or a stationary structure (such as a building, furnace, power plant, geothermal plant, or geyser for example).

[0023] The heat source stream 105 can comprise a heated liquid or gas from which it is desirable to remove heat. Heat exchanger 101 can be, e.g., a shell and tube, plate, condenser/boiler or plate/fin type heat exchanger. The apparatus of figure 1 can form a thermomechanical waste heat recovery system by way of thermal energy conversion 110 from heat recovered from the heat source stream using heat exchanger 101 for example.

[0024] A recuperator 107 is fluidly coupled to and in thermal communication with the first working fluid circuit 103 and is disposed downstream of the heat exchanger 101. Recuperator 107 can be used to recover any useful heat left in the working fluid after conversion 110 of thermal energy, such as in an expansion stage for example.

[0025] In an example, recuperator 107 can comprise a heat exchanger. Such a heat exchanger can be, for example, a counter-flow energy recovery heat exchanger such as a shell and tube, plate, condenser/boiler, micro-tube or plate/fin type heat exchanger. The first working fluid, which carries thermal energy by virtue of its passage through heat exchanger 101 passes through recuperator 107. A first condensing device or condenser 109 is fluidly coupled to and in thermal communication with the first working fluid circuit 103 and disposed downstream of the recuperator 107. Condenser 109 transfers thermal energy from the first working fluid within the first working fluid circuit 103 to a second working fluid circuit 111 comprising a second working fluid. In the example of figure 1, the second working fluid circuit 111 is coupled to and in thermal communication with the first condenser 109. In some examples, circuit 111 can termed or considered as a coolant circuit rather than a working fluid circuit since the second working fluid may not be used in a heat engine or similar. Accordingly, the second working fluid may be considered a coolant.

[0026] A second condenser 113 is fluidly coupled to and in thermal communication with the second working fluid circuit 111 and is disposed downstream of the first condenser 109. A third working fluid circuit 115 comprising a third working fluid is fluidly coupled to and in thermal communication with the second condenser 113. In an example, the third working fluid passes or flows directly over the second condenser 113. Similarly to the second working fluid circuit, in some examples the circuit 115 can termed or considered as a coolant circuit circulating a coolant.

[0027] According to an example, each of the first, second and third working fluids can comprise any one of air,

water, a mixture of water and glycol, a mixture of water, glycol and metallic nano-oxides, butylBenzene, propylbenzene, ethylbenzene, toluene, octamethyl cyclotetrasiloxane (OMTS), butane, isobutene, n-butane, n-hexane, RC-318, R-227ea, R-113, iso-pentane, neo-pentane, R-245fa, R-236ea, C5F12, R236fa, helium, carbon dioxide, supercritical carbon dioxide, other refrigerants, organic fluids and noble gases.

[0028] The second working fluid can be provided from a storage reservoir 117 that is provided as part of the second working fluid circuit 111, and a pump 119 can be used to circulate the second working fluid within the second working fluid circuit 111. In an example, the second and/or third working fluid circuit can be configured as an open circuit in which the second/third working fluids pass to the environment or a waste. Alternatively, the third working fluid circuit 115 can be fluidly coupled to and in thermal communication with the second condenser 113, and form a closed loop circuit.

[0029] Figure 2 is a schematic representation of an apparatus according to an example. Apparatus 200 of figure 2 is a thermomechanical waste heat recovery system. The apparatus of figure 2 (and apparatus 100 of figure 1) can be used to modulate and condition a working fluid, such as a first and/or second and/or third working fluid.

[0030] Apparatus 200 comprises a heat exchanger 201 fluidly coupled to and in thermal communication with a first working fluid circuit 203 comprising a first working fluid. The first working fluid circuit (again, denoted by doubled lined arrows) forms a closed loop circuit in which the first working fluid circulates in the direction depicted by the arrows. Heat exchanger 201 is configured to transfer thermal energy from a heat source stream 205 to the first working fluid within the first working fluid circuit 203.

The heat source stream 205 can be, e.g., an exhaust stream of a mobile platform (such as a land-, air- or water-based vehicular platform for example) or a stationary structure (such as a building for example). The heat source stream 205 can comprise a heated liquid or gas from which it is desirable to remove heat. Heat exchanger 201 can be, e.g., a shell and tube, plate, condenser/boiler, microtube or plate/fin type heat exchanger.

[0031] A recuperator 207 is fluidly coupled to and in thermal communication with the first working fluid circuit 203 and is disposed downstream of the heat exchanger. In an example, recuperator 207 can comprise a heat exchanger such as a counter-flow energy recovery heat exchanger. The first working fluid, which carries thermal energy by virtue of its passage through heat exchanger 201 passes through recuperator 207. A first condensing device or condenser 209 is fluidly coupled to and in thermal communication with the first working fluid circuit 203 and disposed downstream of the recuperator 207. Condenser 209 transfers thermal energy from the first working fluid within the first working fluid circuit 203 to a second working fluid circuit 211 comprising a second working fluid. In the example of figure 2, the second working fluid circuit 211 is coupled to and in thermal communication

with the first condenser 209.

[0032] An expansion device 212 is fluidly coupled to and in thermal communication with the first working fluid circuit 203 and disposed downstream of the heat exchanger 201 and upstream of the recuperator 207. The first working fluid, having absorbed thermal energy from the heat source stream by way of heat exchanger 201 reduces in temperature and enthalpy in expansion device 212 as a result of a reduction in its pressure due to expansion. The reduced pressure/temperature first working fluid then passes through recuperator 207. Accordingly, post expansion the first working fluid passes through recuperator 207 to transfer to transfer excess thermal energy to the first working fluid going into the heat exchanger 201.

[0033] A second condenser 213 is fluidly coupled to and in thermal communication with the second working fluid circuit 211 and is disposed downstream of the first condenser 209. A third working fluid circuit 215 comprising a third working fluid is fluidly coupled to and in thermal communication with the second condenser 213.

[0034] The apparatus 200 further comprises a compression device 214 fluidly coupled to and in thermal communication with the first working fluid circuit 203 and disposed downstream of the expansion device 212 and upstream of the recuperator 207.

[0035] According to an example, each of the first, second and third working fluids can comprise any one of air, water, a mixture of water and glycol, a mixture of water, glycol and metallic nano-oxides, butylbenzene, propylbenzene, ethylbenzene, toluene, octamethyl cyclotetrasiloxane (OMTS), butane, isobutene, n-butane, n-hexane, RC-318, R-227ea, R-113, iso-pentane, neo-pentane, R-245fa, R-236ea, C5F12, R236fa, helium, carbon dioxide, supercritical carbon dioxide, other refrigerants and noble gases.

[0036] The second working fluid can be provided from a storage reservoir or tank 217 that is provided as part of the second working fluid circuit 211, and a pump 219 can be used to circulate the second working fluid within the second working fluid circuit 211. In an example, the third working fluid circuit 215 can be configured as an open circuit in which the third working fluid passes or flows directly over the second condenser 213 to a waste. Alternatively, the third working fluid circuit 215 can be fluidly coupled to and in thermal communication with the second condenser 213, and form a closed loop circuit.

[0037] According to an example, apparatus 200 (and 100) can be used to efficiently remove waste heat from the heat source stream, which may be an exhaust gas for example, by conditioning and modulating at least the first working fluid whereby to increase the temperature and enthalpy thereof. The expansion device 212 is driven by the conditioned first working fluid. In an example, mechanical power can be generated by the expansion device 212 from expanding the conditioned high temperature/enthalpy first working fluid. The mechanical power can be used to power compression device 214 which

can, in an example, be coupled to a generator 216 which generates electrical energy, thereby completing a thermomechanical cycle for converting waste heat energy to electric energy. In some examples, a compression device may not be coupled to a generator. For example, both a compressor and a generator can be coupled to an expander as that is where the mechanical work they use comes from.

[0038] In the example of figure 2, the first condenser 209 is configured as a fluid modulation and conditioning device for conditioning the first working fluid to low temperature and enthalpy. The second working fluid also facilitates the conditioning/modulation of the first working fluid in device 209. Compression device 214 increases the pressure of the conditioned first working fluid and delivers the so-conditioned first working fluid to a fluid modulation and conditioning device configured as the recuperator (or regenerator) 207 wherein the pressured first working fluid is conditioned to moderately increase the temperature and enthalpy of the first working fluid. In an example, working fluid coming out of expansion device 212 has a residual heat which will preheat the working fluid going into the recuperator (207; 107). The same heat exchanger (101/201) can be configured to modulate and condition the first working fluid. The cycle is then repeated.

[0039] The second working fluid is, in an example, a pressurised low temperature/enthalpy fluid drawn from the storage tank 217 by pump 219 to condition the first working fluid in a fluid modulation and conditioning device configured as the first condenser (or evaporator/cooler) 209. In an example, once the second working fluid has been used to condition the first working fluid in the first condenser 209, the second working fluid comprises a high temperature/enthalpy. The high temperature/enthalpy second working fluid can be conditioned in at least one fluid modulation and conditioning device configured as the condenser (or evaporator/cooler) 213 to a low temperature/enthalpy second working fluid. In the example of figure 2, the third working fluid facilitates the conditioning of the high temperature/enthalpy second working fluid in a fluid modulation and conditioning device configured as the condenser (or evaporator/cooler) 213.

[0040] Figure 3 is a schematic representation of an apparatus according to an example. Similarly to the apparatus of figures 1 and 2, apparatus 300 of figure 3 is a thermomechanical waste heat recovery system. In the example of figure 3, a second heat exchanger 301 is fluidly coupled to and in thermal communication with the first working fluid circuit 203. The second heat exchanger 301 is configured to transfer thermal energy from the heat source stream 205 to the first working fluid within the first working fluid circuit 203. A second expansion device 303 is fluidly coupled to and in thermal communication with the first working fluid circuit 203 and is disposed downstream of the first heat exchanger 201 and upstream of the second heat exchanger 301. The use of the second heat exchanger 301 disposed within the heat source

stream flow, and a second expansion device 303 can improve removal of heat from the heat source stream 205 compared to the apparatus of figure 2 for example, in which a single heat exchanger is provided.

[0041] According to an example, with reference to figures 2 and 3, in order to improve the modulation and conditioning of a working fluid, one or more thermoelectric generators configured to heat, cool and/or generate electrical energy can be provided within one or more of the devices of the thermomechanical waste heat recovery systems.

[0042] Thermoelectric generators can be integrated in the fluid modulation and conditioning devices in order to modulate and condition the first, second and third working fluids by way of a thermoelectric operation comprising heating and/or cooling using, e.g., the Peltier effect, and/or generation of electricity using, e.g., the Seebeck effect. In an example, the choice of thermoelectric operation is controlled by a closed-loop feedback control unit or controller 250. The choice of thermoelectric operation can be based on the condition of a working fluid.

[0043] According to an example, a condition of a working fluid, such as one of the first, second and third working fluids can be determined or measured using one or more sensors. A sensor can be provided or embedded in a fluid inlet and/or outlet port of a device of an apparatus 200, 300. A condition of a working fluid can relate to or be defined by one or more of parameters such as the temperature, pressure, salinity, acidity and flow rate and so on of the working fluid.

[0044] Figure 4 is a schematic representation of an apparatus according to an example. Apparatus 400 of figure 4 is a thermomechanical waste heat recovery system. In the example of figure 4, multiple sensors 401 are depicted at the inlets and outlets of the heat exchanger 201, recuperator 207, first condenser 209 and second condenser 213. Sensors may be provided at any one of inlets and outlets in any combination at respective ones of the devices of the prevailing apparatus. In an example, a sensor can determine or measure one of more of the temperature, pressure and flow rate of a working fluid, such as the first and/or second working fluid. In an example, multiple sensors can be provided, each configured to generate a measure of one of temperature, pressure and flow rate of a working fluid, each sensor providing a corresponding condition signal reflecting the parameter it is configured to monitor/measure.

[0045] Sensors to measure the same or similar parameters of the third working fluid can be disposed at appropriate inlet and/or outlet ports of devices in the third working fluid circuit. However, since the third working fluid is largely disposable, rather than being recirculated in a closed loop circuit, measurement of certain parameters thereof may, in some examples, be neglected.

[0046] According to an example, each sensor 401 can generate a condition signal representing the condition of a working fluid (e.g., the first working fluid) at the region of the prevailing working fluid circuit in which the sensor

in question is disposed. The condition signal can comprise data representing one of more of the temperature, pressure, flow rate and other parameters of a working fluid. Thus, given a number of sensors, differences in these values around various points of a working fluid circuit can be determined.

[0047] Each sensor can transmit a condition signal to a controller 250. In an example, a sensor may be wired to or wirelessly coupled to controller 250 for the purposes of data transfer, using a low energy radio frequency communications protocol for example.

[0048] According to an example, controller 250 is configured to control a mode of operation of the or each thermoelectric generator (TEG) in response to a received condition signal. Each sensor may transmit a condition signal at predefined intervals (regular or irregular), may be polled by the controller 250 or a combination of two. A sensor may be configured to transmit a condition signal to the controller outside of any preconfigured transmission window or time in the event that a measured parameter of a working fluid exceeds a predetermined threshold value representing, e.g., a safe operating condition thereof.

[0049] The controller 250 can use the condition signal(s) received from a sensor or sensors to generate a control signal. The control signal can be used to control a mode of operation of the or each TEG. In an example, a control signal can be generated based on a predetermined combination of condition signals from respective sensors. For example, the first heat exchanger 201 (and/or the second heat exchanger 301) may comprise two sensors, one at an inlet and one at an outlet. Each sensor can send a condition signal to the controller 250. The controller 250 can process the received condition signals and generate a control signal based on, e.g., a combination of the process condition signals. For example, a sensor disposed at an inlet of the first heat exchanger 201 may transmit a condition signal representing a temperature of the first working fluid of 40 deg C. A sensor disposed at an outlet of the first heat exchanger 201 may transmit a condition signal representing a temperature of the first working fluid of 140 deg C. The controller can process these condition signals to generate, e.g., a delta value of 100 deg C. This value and/or the value from the inlet and/or outlet sensor can be mapped using, e.g., a look-up table, to a predefined control signal that is configured to control a mode of operation of a TEG. For example, the delta value of 100 deg C, and/or the inlet value of 40 deg C and/or an outlet value of 140 deg C may map to a control signal value that is configured to cause a TEG associated with the first heat exchanger to heat the first working fluid at the outlet or inlet of the first heat exchanger, thereby providing additional heating for the first working fluid before it reaches an expansion device for example.

[0050] The above represents a simple example of the way in which condition signals may be used to control a mode of operation of a TEG. It will be appreciated that

more complex rules may be used that enable outputs from multiple sensors to be processed to generate a control signal. The outputs from sensors from more than one device can be processed in order to generate a control signal, thereby rendering control of a TEG dependent on the condition of a working fluid at multiple points around the corresponding working fluid circuit for example. It is also possible that the control of a TEG associated with a component of one working fluid circuit can be dependent on outputs from sensors associated with components of other working fluid circuits. Broadly speaking, any single output or combination of outputs from any one or more sensors can be used to generate a control signal that can be used for any one or more device or component of an apparatus (e.g., pumps and so on).

[0051] Modulation and conditioning of the primary and secondary working fluids leads to an optimised operation of the thermomechanical waste heat recovery cycle which improves the overall cycle efficiency. Additional cogeneration of electric energy by TEGs integrated in the said fluids modulation and conditioning devices further improves the overall efficiency of the thermomechanical waste heat recovery system.

[0052] Figure 5 is a schematic representation of a thermoelectric generator (TEG) structure according to an example. In the example of figure 5, the TEG structure 509 is depicted as forming part of a device of the first working fluid circuit, which in the case of figure 5 comprises the first condenser 209. Second working fluid 211 enters inlet 505 of the condenser 209 and emerges at outlet 507. The first working fluid enters at inlet 501 of the condenser 209 and emerges at outlet 503. Within the condenser 209, the first working fluid 203 and the second working fluid 211 are in thermal communication with another whereby to enable a transfer of thermal energy therebetween. In the example of figure 5, the first working fluid can follow a predefined pathway such as that defined by, e.g., a conduit 519, with an exemplary direction of flow depicted by the arrows within the body of the condenser 209. The second working fluid may follow a predefined pathway such as that defined by, e.g., a conduit 521 of the condenser as it passes, under pressure, from inlet 505 to outlet 507. It will be appreciated that the opposite relationship between the inlets and outlets for the fluids may be used, such that the second working fluid enters inlet 501 and emerges at outlet 503 and so on.

[0053] A TEG structure 509 can be disposed within the condenser at, near or around one or more of the conduits 519; 521, inlet 501, inlet 505, outlet 503 and outlet 507. TEGs may be provided as discrete elements within the condenser or may be provided as part of one or more of the conduits 519; 521, inlet 501, inlet 505, outlet 503 and outlet 507. In the example of figure 5, a flow regime enables a temperature gradient from the left to the right side of the TEG at all points across its vertical length.

[0054] Controller 250 receives one or more condition signals 509a-d from the sensors 401. As described above, the controller can use the condition signals to gen-

erate a control signal 511. The control signal is provided by the controller 250 to electrodes 513 of TEG structure 509. The electrodes control the action of multiple doped semiconductor elements, such as n-type and p-type doped semiconductor elements (depicted by the alternate patterns of the elements 515 of figure 5), that are configured to heat or cool a working fluid through application of a voltage (e.g., in the form of a suitably configured control signal), or generate electrical energy as a result of exposure to a thermal gradient due to the difference in temperature between, e.g., the first and second working fluids.

[0055] Accordingly, TEG structure 509 comprises a circuit composed of elements 515 comprising materials of different Seebeck coefficients (e.g., p-doped and n-doped semiconductors), such that they are configured to operate according to the thermoelectric effect in which temperature differences can be converted to electric voltage and vice versa. TEG structure 509 can create a voltage when there is a different temperature on each side (e.g., left side vs. right side of the system depicted in figure 5) as a result of the difference in temperature between, e.g., the first and second working fluids. Conversely, when a voltage in the form of the control signal is applied, heat can be transferred from one side to the other, creating a temperature difference, thereby provoking a heating or cooling effect. An insulating and/or protective layer 517 can be provided around the TEG structure.

[0056] With reference to the example described above, if the condition signals received at controller 250 indicate a difference in the temperature of, e.g., the first working fluid between the inlet 501 and the outlet 503 that is above a predetermined threshold temperature value, the controller can generate a control signal configured to cause the TEG structure 509 to enter a cooling mode of operation in which the first working fluid is cooled. As such, the temperature of the first working fluid emerging from the outlet of the condenser will decrease. Consequently, in this regime, the temperature of the second working fluid will increase. A subsequent temperature determination using the sensor at the outlet 503 can provide an indication as to the current temperature of the first working fluid such that, when the predetermined threshold temperature is reached, the controller can cease providing the control signal thereby causing the TEG structure to cease cooling. A similar process can occur in order to heat a working fluid.

[0057] Similar arrangements to that described with reference to figure 5 can be provided for the first and/or second heat exchanger and/or the second condenser 213 and/or recuperator 207 and so on. As such, a fluid modulation and conditioning device configured as apparatus 200, 300, 400 and can modulate and condition working fluids so that at least one of the enthalpy, temperature and pressure drop of the working fluids can be monitored, modulated and conditioned to achieve maximum energy output and efficiency from the thermome-

chanical waste heat recovery system.

[0058] The present disclosure is described with reference to flow charts and/or block diagrams of the method, devices, apparatus and systems according to examples of the present disclosure. Although flow diagrams described may show a specific order of execution, the order of execution may differ from that which is depicted. Blocks described in relation to one flow chart may be combined with those of another flow chart. In some examples, some blocks of the flow diagrams may not be necessary and/or additional blocks may be added. It shall be understood that each flow and/or block in the flow charts and/or block diagrams, as well as combinations of the flows and/or diagrams in the flow charts and/or block diagrams can be realized by machine readable instructions.

[0059] The machine-readable instructions may, for example, be executed by a machine such as a general-purpose computer, user equipment such as a smart device, e.g., a smart phone, a special purpose computer, an embedded processor or processors of other programmable data processing devices to realize the functions described in the description and diagrams. In particular, a processor or processing apparatus may execute the machine-readable instructions. Thus, modules of apparatus (for example, a module implementing a controller) may be implemented by a processor executing machine readable instructions stored in a memory, or a processor operating in accordance with instructions embedded in logic circuitry. The term 'processor' is to be interpreted broadly to include a CPU, processing unit, ASIC, logic unit, or programmable gate set etc. The methods and modules may all be performed by a single processor or divided amongst several processors.

[0060] Such machine-readable instructions may also be stored in a computer readable storage that can guide the computer or other programmable data processing devices to operate in a specific mode. For example, the instructions may be provided on a non-transitory computer readable storage medium encoded with instructions, executable by a processor.

[0061] Figure 6 is a schematic representation of a machine according to an example. In the example of figure 6, the machine comprises a controller 250. The controller 250 may be used with any of the apparatus of figures 1 to 5 in order to receive and process condition signals and/or transmit control signals, as described above. In the example of figure 6, controller 250 comprises a processor 603, and a memory 605 to store instructions 607, executable by the processor 603.

[0062] The controller 250 can comprise a storage 609 that can be used to store data 611 to map a condition signal or signals to a control signal or signals, such as a look-up table for example as described above. The instructions 607, executable by the processor 603, can cause the controller 250 to regulate a mode of operation of at least one thermoelectric generator using a control signal received from a sensor, the control signal representing a condition of the first working fluid and/or the

second working fluid and/or the third working fluid, and/or heat or cool respective ones of the first working fluid and/or the second working fluid and/or the third working fluid, and/or generate electrical energy using the at least one thermoelectric generator, and/or generate the control signal on the basis of one or more condition signals received from one or more sensors provided at at least one of an inlet and outlet of at least one of the heat exchanger, recuperator, first condenser and second condenser.

[0063] Accordingly, the controller 250 can implement a method for modulating and conditioning a working fluid.

[0064] Such machine-readable instructions may also be loaded onto a computer or other programmable data processing devices, so that the computer or other programmable data processing devices perform a series of operations to produce computer-implemented processing, thus the instructions executed on the computer or other programmable devices provide an operation for realizing functions specified by flow(s) in the flow charts and/or block(s) in the block diagrams.

[0065] Further, the teachings herein may be implemented in the form of a computer or software product, such as a non-transitory machine-readable storage medium, the computer software or product being stored in a storage medium and comprising a plurality of instructions, e.g., machine readable instructions, for making a computer device implement the methods recited in the examples of the present disclosure.

[0066] In some examples, some methods can be performed in a cloud-computing or network-based environment. Cloud-computing environments may provide various services and applications via the Internet. These cloud-based services (e.g., software as a service, platform as a service, infrastructure as a service, etc.) may be accessible through a web browser or other remote interface of the user equipment 300 for example. Various functions described herein may be provided through a remote desktop environment or any other cloud-based computing environment.

[0067] While various embodiments have been described and/or illustrated herein in the context of fully functional computing systems, one or more of these exemplary embodiments may be distributed as a program product in a variety of forms, regardless of the particular type of computer-readable-storage media used to actually carry out the distribution. The embodiments disclosed herein may also be implemented using software modules that perform certain tasks. These software modules may include script, batch, or other executable files that may be stored on a computer-readable storage medium or in a computing system. In some embodiments, these software modules may configure a computing system to perform one or more of the exemplary embodiments disclosed herein. In addition, one or more of the modules described herein may transform data, physical devices, and/or representations of physical devices from one form to another.

[0068] The preceding description has been provided to enable others skilled in the art to best utilize various aspects of the exemplary embodiments disclosed herein. This exemplary description is not intended to be exhaustive or to be limited to any precise form disclosed. Many modifications and variations are possible without departing from the spirit and scope of the instant disclosure. The embodiments disclosed herein should be considered in all respects illustrative and not restrictive. Reference should be made to the appended claims and their equivalents in determining the scope of the instant disclosure.

Claims

1. An apparatus, comprising:

a first working fluid circuit comprising a first working fluid;
 a heat exchanger fluidly coupled to and in thermal communication with the first working fluid circuit, the heat exchanger to transfer thermal energy from a heat source stream to the first working fluid within the first working fluid circuit;
 a recuperator fluidly coupled to and in thermal communication with the first working fluid circuit and disposed downstream of the heat exchanger;
 a first condenser fluidly coupled to and in thermal communication with the first working fluid circuit and disposed downstream of the recuperator;
 a second working fluid circuit comprising a second working fluid, the second working fluid circuit coupled to and in thermal communication with the first condenser;
 a second condenser fluidly coupled to and in thermal communication with the second working fluid circuit and disposed downstream of the first condenser; and
 a third working fluid circuit comprising a third working fluid, the third working fluid circuit coupled to and in thermal communication with the second condenser.

2. The apparatus as claimed in claim 1, further comprising:

an expansion device fluidly coupled to and in thermal communication with the first working fluid circuit and disposed downstream of the heat exchanger and upstream of the recuperator.

3. The apparatus as claimed in claim 2, further comprising:

a compression device fluidly coupled to and in thermal communication with the first working fluid circuit and disposed downstream of the expansion device and upstream of the recuperator.

4. The apparatus as claimed in any preceding claim, further comprising:
 a pump fluidly coupled to the second working fluid, the pump to circulate the second working fluid within the second working fluid circuit.

5. The apparatus as claimed in any preceding claim, further comprising:
 a storage vessel fluidly coupled to the second working fluid circuit to store the second working fluid for the second working fluid circuit.

6. The apparatus as claimed in claim 2 or 3, wherein the expansion device is configured to generate mechanical energy from expansion of the first working fluid therein, the apparatus further comprising:
 a generator coupled to the expansion device to convert the mechanical energy to electrical energy.

7. The apparatus as claimed in claim 2 or 3, wherein the expansion device is configured to generate mechanical energy from expansion of the first working fluid therein, and wherein the compression device is coupled to the expansion device whereby to receive mechanical energy therefrom, the compression device configured to compress the first working fluid for the recuperator.

8. The apparatus as claimed in any preceding claim, wherein at least one of the heat exchanger, recuperator, first condenser and second condenser comprise a thermoelectric generator fluidly coupled thereto and in thermal communication therewith.

9. The apparatus as claimed in claim 8, further comprising:
 a controller to control a mode of operation of the or each thermoelectric generator in response to a condition signal generated by a sensor configured to generate a measure representing a condition of the first working fluid.

10. The apparatus as claimed in claim 9, wherein the sensor is provided at one of an inlet and outlet of at least one of the heat exchanger, recuperator, first condenser and second condenser.

11. The apparatus as claimed in any of claims 8 to 10, wherein the or each thermoelectric generator is configured to heat and/or cool at least one of the first, second and third working fluids, and/or generate electricity therefrom.

12. The apparatus as claimed in any preceding claim, further comprising:
 a second heat exchanger fluidly coupled to and in thermal communication with the first working fluid circuit, the second heat exchanger to transfer ther-

mal energy from the heat source stream to the first working fluid within the first working fluid circuit.

13. The apparatus as claimed in claim 12, further comprising: 5
 a second expansion device fluidly coupled to and in thermal communication with the first working fluid circuit and disposed downstream of the heat exchanger and upstream of the second heat exchanger. 10
14. A method for modulating and conditioning a working fluid, the method comprising:

heating a first mass flow of a first working fluid 15
 in a heat exchanger fluidly coupled to and in thermal communication with a first working fluid circuit and a heat source stream, wherein the heat exchanger is configured to transfer thermal energy from the heat source stream to the first 20
 mass flow of the first working fluid within the first working fluid circuit;
 transferring, via a recuperator, heat from the first mass flow downstream of the heat exchanger and upstream of a first condenser to the first 25
 mass flow downstream of the first condenser and upstream of the heat exchanger;
 condensing the first mass flow of the first working fluid in a first condenser fluidly coupled to the first working fluid circuit; 30
 condensing a second mass flow of a second working fluid of a second working fluid circuit fluidly coupled to and in thermal communication with the first condenser, the second mass flow condensed using a second condenser fluidly 35
 coupled to and in thermal communication with the second working fluid circuit and disposed downstream of the first condenser;
 conditioning, using a third mass flow of a third working fluid within a third working fluid circuit 40
 coupled to and in thermal communication with the second condenser, the second mass flow of the second working fluid.

15. A non-transitory machine-readable storage medium 45
 encoded with instructions for modulating and conditioning a working fluid, the instructions executable by a processor of a controller of an apparatus as claimed in any one of claims 1 to 13, whereby to cause the controller to: 50
 regulate a mode of operation of at least one thermoelectric generator using a control signal received from a sensor, the control signal representing a condition of the first working fluid and/or the second working fluid and/or the third working fluid. 55

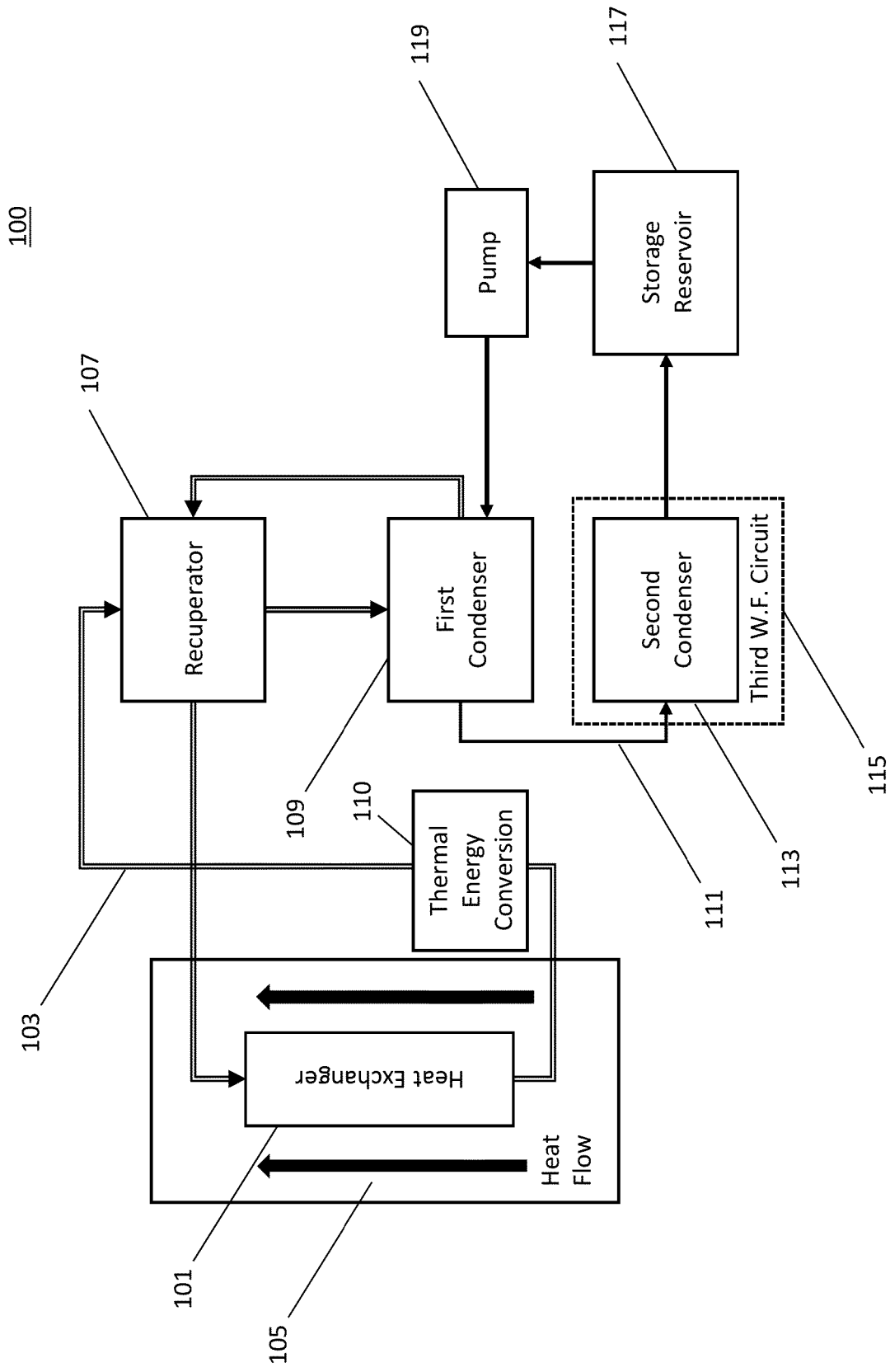


Figure 1

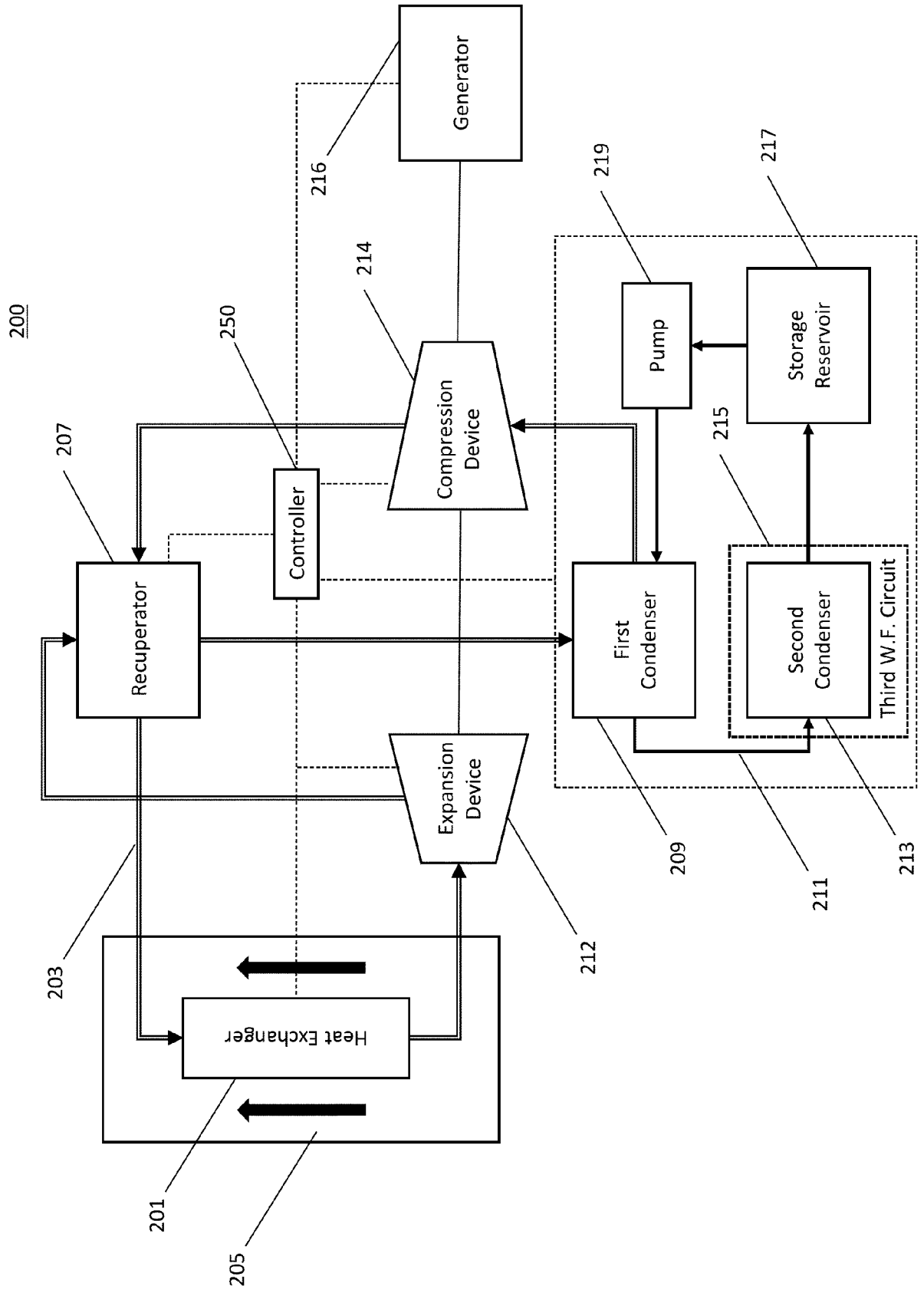


Figure 2

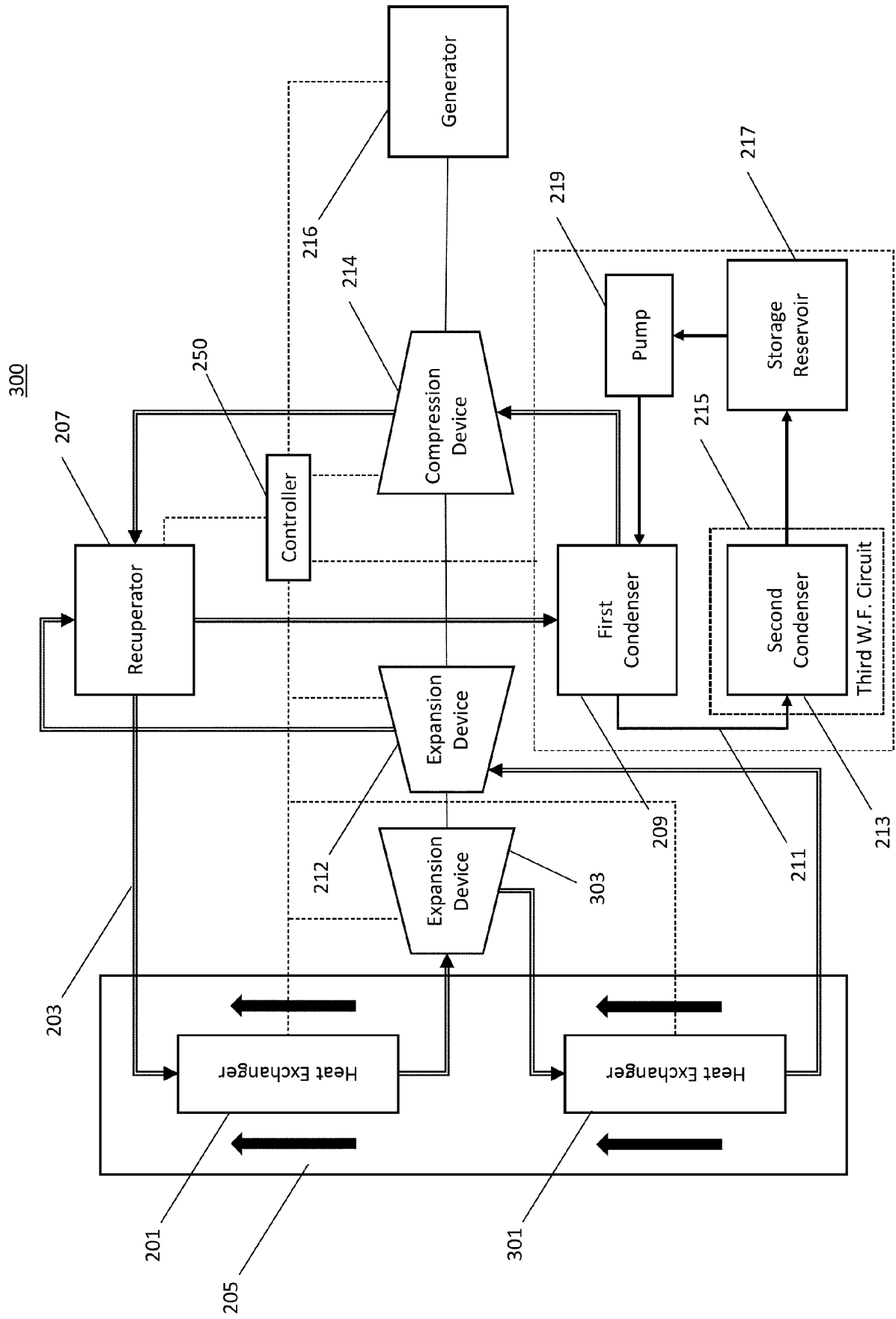


Figure 3

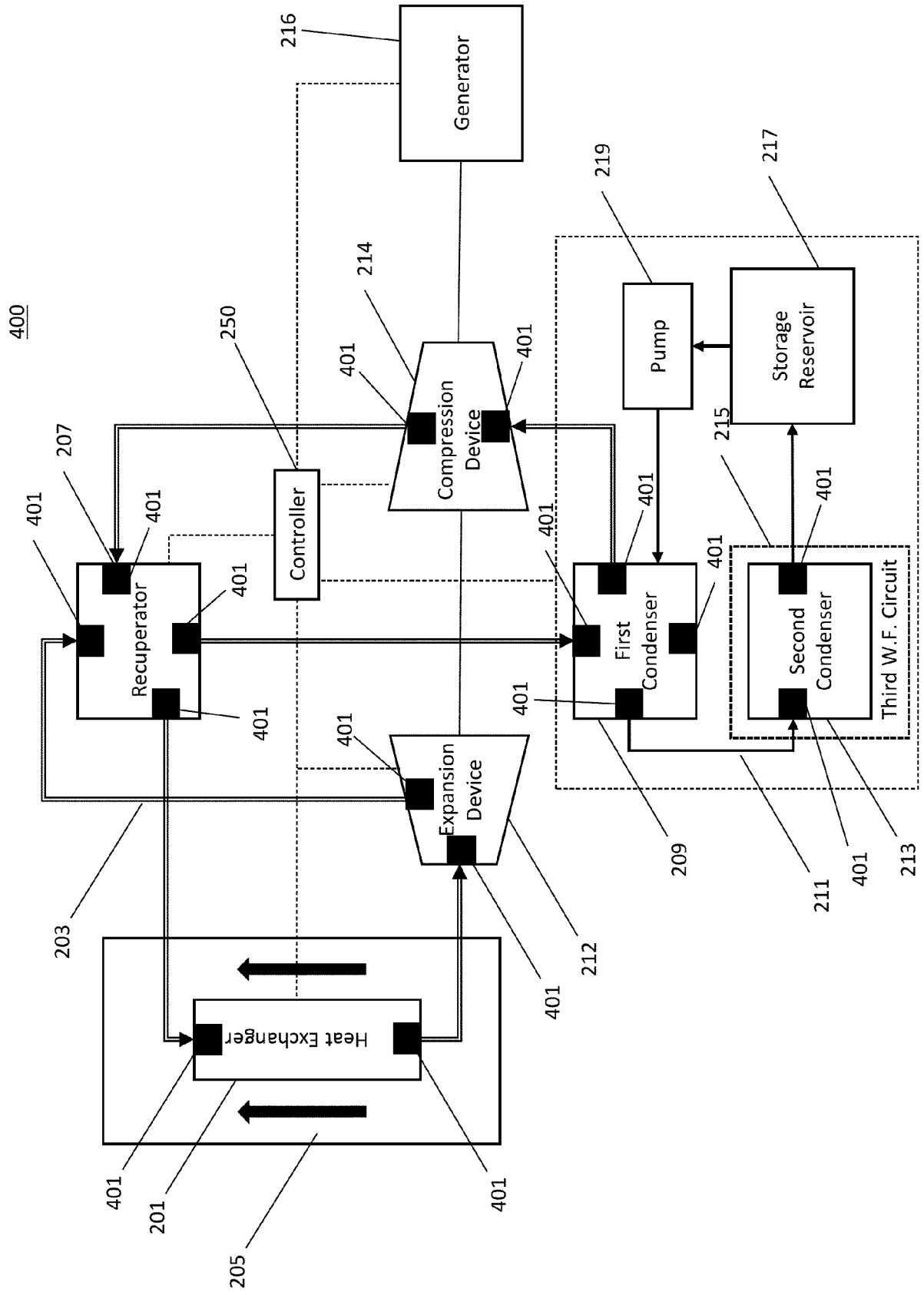
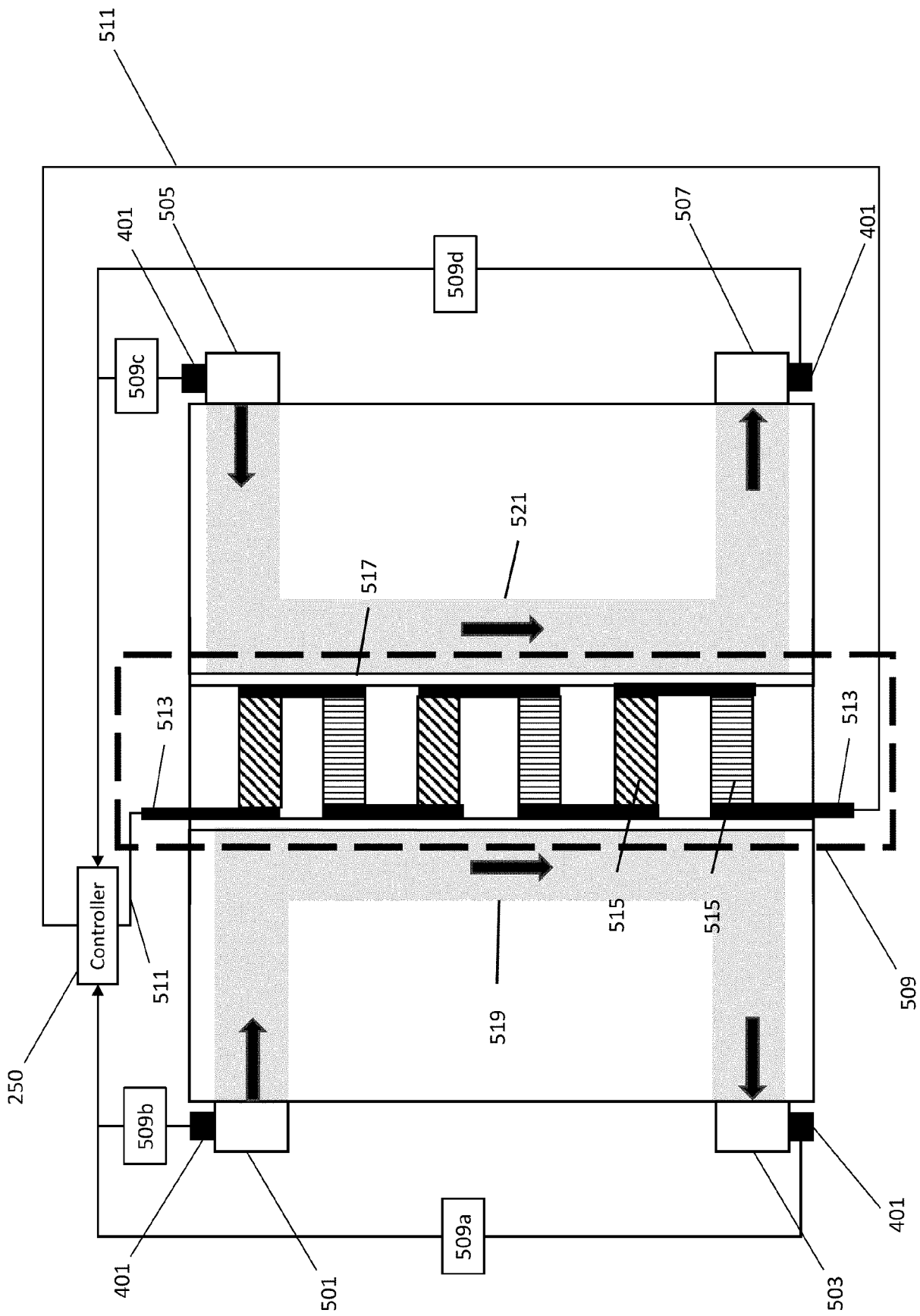


Figure 4



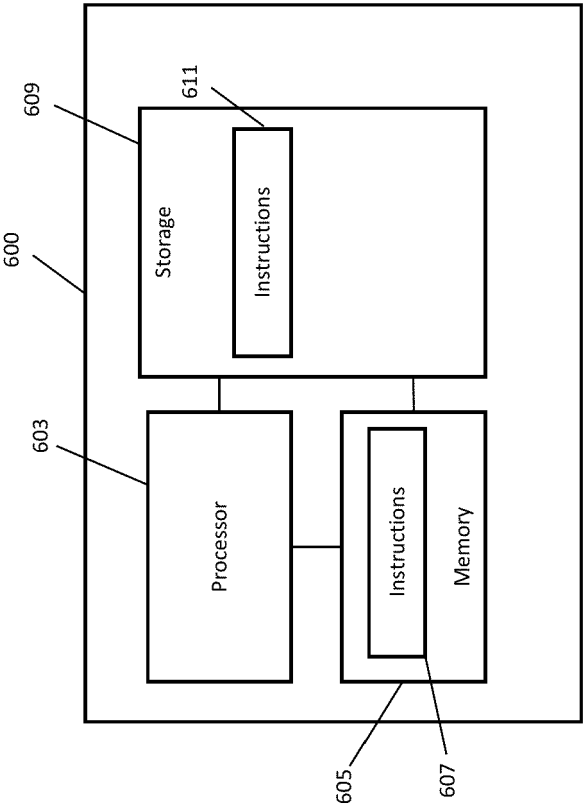


Figure 6



EUROPEAN SEARCH REPORT

Application Number

EP 21 27 5127

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EPO FORM 1503 03.82 (P04C01)

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	EP 3 572 329 A1 (ROLLS ROYCE PLC [GB]) 27 November 2019 (2019-11-27)	1-12, 14, 15	INV. F25B11/02
A	* (see Fig. 6 and Par. 28-53); paragraph [0028] - paragraph [0053]; figure 6 *	13	F25B25/00 F25B40/00 B64D13/06
X	EP 3 444 448 A1 (GENERAL ELECTRIC TECHNOLOGY GMBH [CH]) 20 February 2019 (2019-02-20)	1-12, 14, 15	
A	* paragraph [0032] - paragraph [0046]; figure 1 *	13	
A	WO 2014/165144 A1 (ECHOGEN POWER SYSTEMS LLC [US]; BOWAN BRETT A [US]) 9 October 2014 (2014-10-09)	1-15	
	* paragraph [0022] - paragraph [0058]; figure 1 *		
A	US 9 341 084 B2 (ECHOGEN POWER SYSTEMS LLC [US]) 17 May 2016 (2016-05-17)	1-15	
	* column 5, line 38 - column 15, line 60; figure 1 *		TECHNICAL FIELDS SEARCHED (IPC)
A	US 2020/292217 A1 (WAGNER THOMAS [US] ET AL) 17 September 2020 (2020-09-17)	1-15	F25B B64D
	* paragraph [0168] - paragraph [0181]; figure 25 *		
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 14 February 2022	Examiner Gasper, Ralf
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 21 27 5127

5

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 3572329 A1	27-11-2019	EP 3572328 A1	27-11-2019
		EP 3572329 A1	27-11-2019
		US 2019359339 A1	28-11-2019
		US 2019359340 A1	28-11-2019
EP 3444448 A1	20-02-2019	CL 2020000390 A1	28-08-2020
		CN 111164276 A	15-05-2020
		EP 3444448 A1	20-02-2019
		EP 3669056 A1	24-06-2020
		JP 2020531779 A	05-11-2020
		MA 49892 A	24-06-2020
		US 2020248592 A1	06-08-2020
		WO 2019034536 A1	21-02-2019
WO 2014165144 A1	09-10-2014	US 2016061055 A1	03-03-2016
		WO 2014165144 A1	09-10-2014
US 9341084 B2	17-05-2016	US 2014102101 A1	17-04-2014
		WO 2014059231 A1	17-04-2014
US 2020292217 A1	17-09-2020	NONE	