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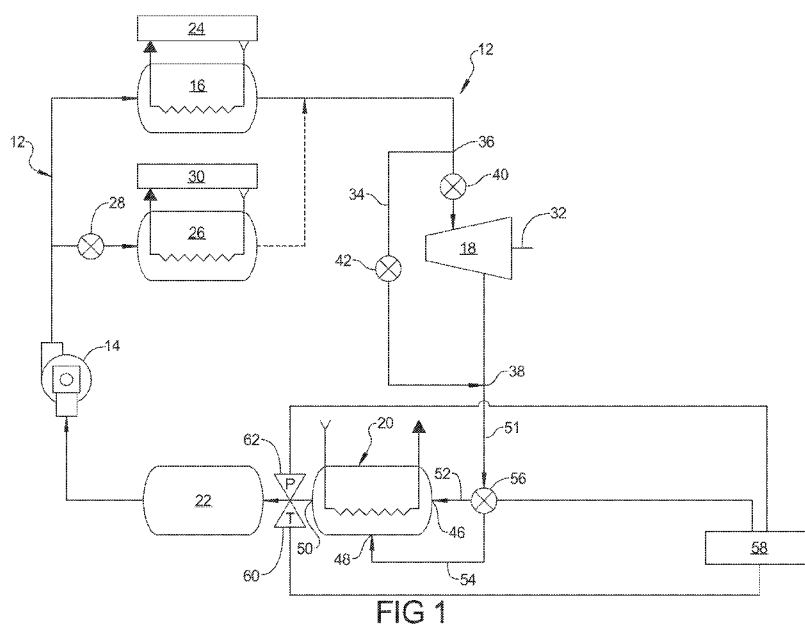
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[Continued on next page]

(54) Title: WASTE HEAT RECOVERY SYSTEM



(57) Abstract: A waste heat recovery system may include a pump, first and second heat exchangers, an expander, and a valve. The first heat exchanger receives working fluid from the pump. The expander receives working fluid from the first heat exchanger and includes an output shaft that is powered by the flow of working fluid through the expander. The second heat exchanger may include a first fluid path and a second fluid path that is shorter than the first fluid path. The valve controls fluid flow through the first and second fluid paths. A sensor may measure a parameter of the working fluid that indicates whether the working fluid is in a gaseous state, a liquid state or a mixture of gas and liquid. A control module in communication with the sensor may control a position of the valve based on a value of the parameter measured by the sensor.

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- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
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WASTE HEAT RECOVERY SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Utility Application No. 14/633,250, filed February 27, 2015. The entire disclosure of the above
5 application is incorporated herein by reference.

FIELD

[0002] The present disclosure relates to a waste heat recovery system, and particularly to a waste heat recovery system for a vehicle.

BACKGROUND

10 **[0003]** This section provides background information related to the present disclosure and is not necessarily prior art.

[0004] A waste heat recovery system (e.g., a Rankine cycle system) can be used in a vehicle to absorb heat from a vehicle fluid that carries waste heat (e.g., exhaust gas, compressed engine-intake air, engine coolant, etc.) and
15 convert the heat energy from the fluid into usable energy. For example, a waste heat recovery system can use energy from waste heat to provide power to a vehicle propulsion system (e.g., an electric motor that provides motive power to the vehicle) and/or provide power to an electrical generator to charge batteries and/or operate electrical accessories of the vehicle. Heat exchangers are
20 important components of waste heat recovery systems. Improvements to the state of the art may yield higher energy recovery and thus improve the energy-efficiency of vehicles.

SUMMARY

[0005] This section provides a general summary of the disclosure, and is
25 not a comprehensive disclosure of its full scope or all of its features.

[0006] In one form, the present disclosure provides, a waste heat recovery system that may include a pump, first and second heat exchangers, an

expander, and a valve. The first heat exchanger is disposed downstream of the pump and receives working fluid from the pump. The expander is disposed downstream of the first heat exchanger and receives working fluid from the first heat exchanger. The expander includes an output shaft that is powered by the working fluid flowing through the expander. The second heat exchanger is disposed downstream of the expander and receives working fluid from the expander. The second heat exchanger may include a first inlet, a second inlet and an outlet. A first fluid path through the second heat exchanger between the first inlet and the outlet may have a first length. A second fluid path through the second heat exchanger between the second inlet and the outlet may have a second length that is shorter than the first length. The valve may be disposed upstream of the outlet of the second heat exchanger and downstream of the expander and controls fluid flow through the first and second inlets.

[0007] In some configurations, working fluid in the first heat exchanger absorbs heat from a fluid (e.g., engine exhaust gas, compressed air, and engine coolant) that is separate from the working fluid.

[0008] In some configurations, the valve is disposed upstream of the first and second inlets of the second heat exchanger.

[0009] In some configurations, the second fluid path includes only a portion of the first fluid path.

[0010] In some configurations, the valve is movable between a first position in which working fluid is allowed to flow through the first inlet and is prevented from flowing through the second inlet, a second position in which working fluid is allowed to flow through the second inlet and is prevented from flowing through the first inlet, and a third position in which working fluid is allowed to flow through the first inlet and the second inlet.

[0011] In some configurations, the waste heat recovery system includes a sensor and a control module. The sensor may be disposed downstream of the second heat exchanger and upstream of the pump. The control module is in communication with the sensor and controls operation of the valve based on data received from the sensor.

[0012] In some configurations, the sensor is a temperature sensor. The control module may control the valve based on a comparison of data from the sensor and a predetermined temperature value indicative of full condensation of the working fluid exiting the outlet of the second heat exchanger.

5 **[0013]** In some configurations, the first and second inlets and the outlet are formed in a vehicle panel disposed on an underbody of a vehicle such that heat from the working fluid within the second heat exchanger is transferred to air flowing between the underbody of the vehicle and a ground surface upon which the vehicle is situated.

10 **[0014]** In some configurations, the vehicle panel could be or include a skid plate, a floor pan, a belly pan, and/or an under-floor aerodynamic panel.

[0015] In some configurations, the second heat exchanger is integrally formed with a body panel of a vehicle. For example, the body panel could include or be a part of an aerodynamic fairing, such as a roof fairing of a commercial truck (e.g., a Class 8 truck).

15 **[0016]** In another form, the present disclosure provides a waste heat recovery system that may include a pump, first and second heat exchangers, an expander, and a valve. The first heat exchanger is disposed downstream of the pump and receives working fluid from the pump. The expander is disposed downstream of the first heat exchanger and receives working fluid from the first heat exchanger. The expander includes an output shaft that is powered by the working fluid flowing through the expander. The second heat exchanger may include a first fluid path having a first length and a second fluid path having a second length that is shorter than the first length. The valve may be disposed downstream of the expander and controls fluid flow through the first and second fluid paths. A sensor may be disposed downstream of the first and second fluid paths and upstream of the pump. The sensor measuring a parameter (e.g., temperature or pressure) of the working fluid indicating whether the working fluid is in a gaseous state, a liquid state or a mixture of gas and liquid. A control module in communication with the sensor and the valve may control a position of the valve based on a value of the parameter measured by the sensor.

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[0017] In some configurations, the valve is disposed within the second heat exchanger between an inlet of the second heat exchanger and an outlet of the second heat exchanger.

5 **[0018]** In some configurations, the second heat exchanger includes first inlet, a second inlet and an outlet. The first fluid path may extend between the first inlet and the outlet. The second fluid path may extend between the second inlet and the outlet.

[0019] In some configurations, the valve is disposed upstream of the first and second inlets.

10 **[0020]** In some configurations, the valve is movable between a first position in which working fluid is allowed to flow through the first inlet and is prevented from flowing through the second inlet, a second position in which working fluid is allowed to flow through the second inlet and is prevented from flowing through the first inlet, and a third position in which working fluid is
15 allowed to flow through the first inlet and the second inlet.

[0021] In some configurations, the sensor is a temperature sensor, and the control module controls the valve based on a comparison of data from the sensor and a predetermined temperature value indicative of full condensation of the working fluid exiting the second heat exchanger.

20 **[0022]** In some configurations, the first and second fluid paths are formed in a vehicle panel disposed on an underbody of a vehicle such that heat from the working fluid within the second heat exchanger is transferred to air flowing between the underbody of the vehicle and a ground surface upon which the vehicle is situated.

25 **[0023]** In some configurations, the vehicle panel could be or include a skid plate, a floor pan, a belly pan, and/or an under-floor aerodynamic panel.

[0024] In some configurations, the second heat exchanger is integrally formed with a body panel of a vehicle. For example, the body panel could include or be a part of an aerodynamic fairing, such as a roof fairing of a
30 commercial truck (e.g., a Class 8 truck).

[0025] In another form, the present disclosure provides a waste heat recovery system that may include a pump, first and second heat exchangers,

and an expander. The first heat exchanger is disposed downstream of the pump and receives working fluid from the pump. The expander is disposed downstream of the first heat exchanger and receives working fluid from the first heat exchanger. The expander includes an output shaft that is powered by the working fluid flowing through the expander. The second heat exchanger is disposed downstream of the expander and receives working fluid from the expander. The second heat exchanger may be formed in a vehicle panel disposed on an underbody of a vehicle such that heat from the working fluid within the second heat exchanger is transferred to air flowing between the underbody of the vehicle and a ground surface upon which the vehicle is situated.

[0026] In some configurations, the vehicle panel includes or is a part of a skid plate, a floor pan, a belly pan, and/or an under-floor aerodynamic panel.

[0027] In some configurations, the second heat exchanger includes a first inlet, a second inlet and an outlet. A first fluid path extending through the second heat exchanger between the first inlet and the outlet may have a first length. A second fluid path extending through the second heat exchanger between the second inlet and the outlet may have a second length that is shorter than the first length.

[0028] In some configurations, the waste heat recovery system includes a valve disposed upstream of the outlet of the second heat exchanger and downstream of the expander and controlling fluid flow through the first and second inlets.

[0029] In some configurations, the valve is disposed upstream of the first and second inlets.

[0030] In some configurations, the second fluid path includes only a portion of the first fluid path.

[0031] In some configurations, the valve is movable between a first position in which working fluid is allowed to flow through the first inlet and is prevented from flowing through the second inlet, a second position in which working fluid is allowed to flow through the second inlet and is prevented from

flowing through the first inlet, and a third position in which working fluid is allowed to flow through the first inlet and the second inlet.

[0032] In some configurations, valves could be disposed upstream and downstream of the second heat exchanger to proportion the flow from upstream and downstream of the second heat exchanger. For example, the valves upstream and downstream of the second heat exchanger could be controlled to selectively achieve either a condensing condition of the fluid flowing through the second heat exchanger or a supercooling condition of the fluid flowing through the second heat exchanger, as desired.

[0033] In some configurations, the waste heat recovery system includes a sensor disposed downstream of the second heat exchanger and upstream of the pump; and a control module in communication with the sensor and controlling operation of the valve based on data received from the sensor.

[0034] In some configurations, the sensor is a temperature sensor. The control module may control the valve based on a comparison of data from the sensor and a predetermined temperature value indicative of full condensation of the working fluid exiting the outlet of the second heat exchanger.

[0035] Further areas of applicability will become apparent from the description provided herein. The description and specific examples in this summary are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

DRAWINGS

[0036] The drawings described herein are for illustrative purposes only of selected embodiments and not all possible implementations, and are not intended to limit the scope of the present disclosure.

[0037] Figure 1 is a schematic representation of a waste heat recovery system according to the principles of the present disclosure;

[0038] Figure 2 is a schematic representation of a heat exchanger according to the principles of the present disclosure;

[0039] Figure 3 is a schematic representation of another heat exchanger according to the principles of the present disclosure;

[0040] Figure 4 is a schematic side view of a vehicle having a heat exchanger according to the principles of the present disclosure;

[0041] Figure 5 is a schematic plan view of the heat exchanger of Figure 4; and

5 **[0042]** Figure 6 is a schematic cross-sectional view of the heat exchanger of Figure 4.

[0043] Corresponding reference numerals indicate corresponding parts throughout the several views of the drawings.

DETAILED DESCRIPTION

10 **[0044]** Example embodiments will now be described more fully with reference to the accompanying drawings.

[0045] Example embodiments are provided so that this disclosure will be thorough, and will fully convey the scope to those who are skilled in the art. Numerous specific details are set forth such as examples of specific
15 components, devices, and methods, to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to those skilled in the art that specific details need not be employed, that example embodiments may be embodied in many different forms and that neither should be construed to limit the scope of the disclosure. In some example embodiments, well-known
20 processes, well-known device structures, and well-known technologies are not described in detail.

[0046] The terminology used herein is for the purpose of describing particular example embodiments only and is not intended to be limiting. As used herein, the singular forms "a," "an," and "the" may be intended to include the
25 plural forms as well, unless the context clearly indicates otherwise. The terms "comprises," "comprising," "including," and "having," are inclusive and therefore specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups
30 thereof. The method steps, processes, and operations described herein are not to be construed as necessarily requiring their performance in the particular order

discussed or illustrated, unless specifically identified as an order of performance. It is also to be understood that additional or alternative steps may be employed.

[0047] When an element or layer is referred to as being "on," "engaged to," "connected to," or "coupled to" another element or layer, it may be directly on, engaged, connected or coupled to the other element or layer, or intervening elements or layers may be present. In contrast, when an element is referred to as being "directly on," "directly engaged to," "directly connected to," or "directly coupled to" another element or layer, there may be no intervening elements or layers present. Other words used to describe the relationship between elements should be interpreted in a like fashion (e.g., "between" versus "directly between," "adjacent" versus "directly adjacent," etc.). As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

[0048] Although the terms first, second, third, etc. may be used herein to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers and/or sections should not be limited by these terms. These terms may be only used to distinguish one element, component, region, layer or section from another region, layer or section. Terms such as "first," "second," and other numerical terms when used herein do not imply a sequence or order unless clearly indicated by the context. Thus, a first element, component, region, layer or section discussed below could be termed a second element, component, region, layer or section without departing from the teachings of the example embodiments.

[0049] Spatially relative terms, such as "inner," "outer," "beneath," "below," "lower," "above," "upper," and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. Spatially relative terms may be intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as "below" or "beneath" other elements or features would then be oriented "above" the other elements or features. Thus, the example term "below" can encompass both an orientation of above and below. The device may be otherwise oriented (rotated 90 degrees or

at other orientations) and the spatially relative descriptors used herein interpreted accordingly.

[0050] With reference to Figure 1, a Rankine cycle waste heat recovery system 10 is provided that may include a fluid circuit 12 having a pump 14, an evaporator 16, an expander 18, a condenser 20 and an accumulator 22. The pump 14 can be battery-powered or powered by an engine of a vehicle in which the system 10 is installed. The pump 14 may circulate a working fluid (e.g., a refrigerant) through the fluid circuit 12.

[0051] The evaporator 16 is disposed downstream of the pump 14 and receives working fluid discharged from the pump 14. Working fluid flowing through the evaporator 16 may absorb heat from a separate fluid (e.g., exhaust gas, compressed air, engine coolant, etc.) from a source 24. For example, the source 24 could be or include a vehicle system such as an engine exhaust system, an exhaust gas recirculation (EGR) system, an engine air-induction system, or an engine coolant circuit. The fluid from source 24 flows through the evaporator 16 in a conduit that is fluidly isolated from the working fluid but in a heat transfer relationship with the working fluid such that heat is transferred from the fluid (i.e., the fluid from source 24) to the working fluid within the evaporator 16.

[0052] In some configurations, the fluid circuit 12 may include a secondary evaporator 26 in parallel with the evaporator 16. A control valve 28 can control an amount of working fluid from the pump 14 that is allowed to flow through the secondary evaporator 26. Working fluid in the secondary evaporator 26 may absorb heat from another fluid (e.g., exhaust gas, compressed air, engine coolant, etc.) from another source 30 in the manner described above. The source 30 could be or include a vehicle system such as an engine exhaust system, an exhaust gas recirculation (EGR) system, an engine air-induction system, or an engine coolant circuit.

[0053] Working fluid from one or both of the evaporators 16, 26 may flow to the expander 18. Working fluid flowing through the expander 18 may power an output shaft 32 of the expander 18. For example, the output shaft 32 may be configured to power a vehicle propulsion system and/or power an electrical

generator to charge batteries and/or operate electrical accessories of the vehicle. In some configurations, the fluid circuit 12 could include a bypass conduit 34 that extends from a first location 36 between the expander 18 and the evaporators 16, 26 and a second location 38 downstream of the expander 18.

5 Control valves 40, 42 may control an amount of working fluid that is allowed to flow through the expander 18 and an amount of working fluid that is allowed to bypass the expander 18 in the bypass conduit 34.

[0054] The condenser 20 is disposed downstream of the expander 18 and the second location 38 and receives working fluid from the expander 18 and/or
10 the bypass conduit 34. Heat from the working fluid flowing through the condenser 20 may be transferred to ambient air flowing around the outside of the condenser 20 and/or to a coolant that flows through a conduit in the condenser 20 that is fluidly isolated from the working fluid, for example. Cooled working fluid exiting the condenser 20 may flow to the accumulator 22 before flowing
15 back to the pump 14.

[0055] In the particular configurations shown in Figures 1 and 2, the condenser 20 includes a working fluid conduit 44 (Figure 2) having a first inlet 46, a second inlet 48 and an outlet 50. The fluid circuit 12 may include a supply conduit 51, a first conduit 52, a second conduit 54 and a control valve 56
20 disposed between the expander 18 and the condenser 20. The supply conduit 51 receives working fluid from the expander 18 and the bypass conduit 34 and routes the working fluid to the control valve 56. The first conduit 52 fluidly connects the control valve 56 with the first inlet 46. The second conduit 54 fluidly connects the control valve 56 with the second inlet 48.

25 [0056] The control valve 56 may be movable among a plurality of positions to control the flow of working fluid through the first and second conduits 52, 54. In a first position of the control valve 56, working fluid is allowed to flow from the supply conduit 51 through the first conduit 52 and into the first inlet 46 and is prevented from flowing into the second conduit 54 and the second inlet
30 48. In a second position of the control valve 56, working fluid is allowed to flow from the supply conduit 51, through the second conduit 54 and into the second inlet 48 and is prevented from flowing into the first inlet 46. In a third position of

the control valve 56, working fluid is allowed to flow from the supply conduit 51, through both of the first and second conduits 52, 54 and into both of the first and second inlets 46, 48. It will be appreciated that the control valve 56 could be movable to a plurality of positions between the first and third positions and to a plurality of positions between the second and third positions to control the flow of working fluid in a desired manner. The control valve 56 can be a solenoid valve, for example, or any other suitable electromechanical valve.

[0057] As shown in Figure 2, the working fluid conduit 44 of the condenser 20 may be a serpentine conduit defining a first fluid path extending from the first inlet 46 to the outlet 50 and a second fluid path (including a portion of the first fluid path) extending from the second inlet 48 to the outlet 50. As shown in Figure 2, the first fluid path has a longer length than the second fluid path. Accordingly, the control valve 56 can be actuated to control the length of the working fluid conduit 44 through which the working fluid flows.

[0058] A control module 58 may control operation of the control valve 56 and can cause the control valve 56 to move among the various positions described above to control the flow of working fluid through the first and second conduits 52, 54. The control module 58 may be in communication with one or more sensors and may control operation of the control valve 56 based on information received from the one or more sensors.

[0059] For example, in the configuration shown in Figure 1, a temperature sensor 60 and a pressure sensor 62 may be disposed between the outlet 50 of the condenser 20 and the accumulator 22. The temperature sensor 60 may measure a temperature of the working fluid exiting the condenser 20 and communicate that temperature data to the control module 58 intermittently or continuously. The pressure sensor 62 may measure a pressure of the working fluid exiting the condenser 20 and communicate that pressure data to the control module 58 intermittently or continuously. The control module 58 may control the operation of the control valve 56 based on the data from the temperature and pressure sensors 60, 62. That is, the control module 58 can position or modulate the control valve 56 so that only enough heat energy to cause a phase change of the working fluid at the coldest expected ambient air temperature.

The control module 58 may compare the temperature data received from the temperature sensor 60 with a predetermined temperature value (e.g., a temperature threshold corresponding to a phase change of the working fluid from gaseous state to liquid state at the current pressure sensed by the pressure sensor 62) and position or modulate the control valve 56 to achieve adequate condensation of the working fluid at the current working fluid pressure (determined by the pressure sensor 62) while not overcooling the working fluid or cooling the working fluid beyond a temperature that is necessary or desired. It may be desirable to control the valve 56 so that the working fluid is as hot as possible without being in a gaseous state.

[0060] While the control valve 56 is described above as being an actively controlled electromechanical valve (controlled in response to data from sensors 60, 62), in some configurations, the valve 56 could be a passive valve such as a mechanical thermostatically actuated device that is actuated in response to working fluid exiting the condenser 20 falling below or rising above one or more predetermined temperatures. In some configurations, instead of the sensors 60, 63, the control valve 56 could be actuated by a gas/liquid sensor operable to sense whether fluid exiting the condenser 20 is in a gaseous state or a liquid state. For example, such a gas/liquid sensor could include a float that would sink in gas and float in liquid. Movement of the float would cause the valve 56 to move between open and closed positions allowing and restricting fluid flow through the second conduit 54.

[0061] Referring now to Figure 3, another condenser 120 is provided that may be incorporated into the fluid circuit 12 instead of the condenser 20, the first and second conduits 52, 54 and the control valve 56. The condenser 120 may include an inlet 146, an outlet 150, a pair of headers 152, 154 and a plurality of tubes 158 fluidly connecting the headers 152, 154. The inlet 146 may be connected to the supply conduit 51 (Figure 1) such that all of the working fluid flowing through the fluid circuit 12 flows through the inlet 146. One or more control valves 156 may be disposed in the one or both of the headers 152, 154 and/or in one or more of the tubes 158. Closing one or more of the control

valves 156 restricts the flow of working fluid through one or more of the tubes 158, thereby reducing the cooling capacity of the condenser 120.

[0062] The one or more control valves 156 may be in communication with the control module 58. The control module 58 may control operation of the one or more control valves 156 based on information received from the temperature sensor 60 disposed at or downstream of the outlet 150 in the manner described above. That is, the control module 58 may modulate or adjust the position of one or more of the control valves 156 based on a comparison of the data from temperature sensor 60 and the predetermined temperature value to achieve adequate condensation of the working fluid while not overcooling the working fluid or cooling the working fluid beyond a temperature that is necessary or desired. It may be desirable to control the one or more valves 156 so that the working fluid is as hot as possible without being in a gaseous state.

[0063] Referring now to Figure 4, an automotive vehicle 200 is provided that includes a waste heat recovery system 210 incorporated therein. The waste heat recovery system 210 can be similar or identical to the system 10 described above. Therefore, similar features will not be described again in detail. Like the system 10, the system 210 includes a fluid circuit 212 including a condenser 220 that cools working fluid downstream of an expander 218.

[0064] In the configuration shown in Figure 4, the condenser 220 (e.g., a condenser similar or identical to either of the condensers 20, 120) is incorporated into or formed integrally with a vehicle body panel disposed on an underbody of the vehicle such as a skid plate, a floor pan, a belly pan, or an under-floor aerodynamic panel. Unlike conventional condensers mounted at a front-end grille of the vehicle, the condensers 20, 120 shown in Figure 4 have a minimal impact on aerodynamic drag on the vehicle 200, while still being exposed to a flow of air while the vehicle 200 is in motion. Furthermore, integrally forming or incorporating the condenser 220 into the vehicle body panel will reduce the number of parts in the vehicle 200 by adding functionality to a preexisting component, which can reduce cost and complexity of the vehicle 200.

[0065] The condenser 220 can be incorporated into or formed integrally with a vehicle body panel in a number of ways. For example, tubes (not shown) can be fused, brazed, welded or otherwise joined to one or more external surfaces of such the vehicle body panel. As another example, the condenser
5 220 could include first and second panels 222, 224 (Figures 5 and 6) that are fused, brazed, welded or otherwise joined together and defining one or more working fluid conduits 244 therebetween. As shown in Figures 5 and 6, one or both of the panels 222, 224 may include flow diverters 226 that may define a serpentine flow path of the working fluid conduit 244. The working fluid conduit
10 244 may include first and second inlets 246, 248 and an outlet 250. External surfaces of the first and second panels 222, 224 could be shaped and contoured to correspond to desired shapes and contours of the particular vehicle body panel with which the condenser 220 is incorporated or integrated. For example, the external surfaces of the first and second panels 222, 224 can be
15 aerodynamically shaped to aerodynamically shield other underbody components of the vehicle 200.

[0066] While the condenser 220 is depicted in Figure 5 as having two inlets 246, 248, in some configurations, the condenser 220 could have only a single inlet and a single outlet or any other number of inlets and outlets. Further,
20 in some configurations, the system 210 may not include any control valves to regulate an amount of the condenser 220 through which the working fluid flows.

[0067] In this application, including the definitions below, the term “module” or “controller” may be replaced with the term “circuit.” The term “module” may refer to, be part of, or include: an Application Specific Integrated
25 Circuit (ASIC); a digital, analog, or mixed analog/digital discrete circuit; a digital, analog, or mixed analog/digital integrated circuit; a combinational logic circuit; a field programmable gate array (FPGA); a processor circuit (shared, dedicated, or group) that executes code; a memory circuit (shared, dedicated, or group) that stores code executed by the processor circuit; other suitable hardware
30 components that provide the described functionality; or a combination of some or all of the above, such as in a system-on-chip.

[0068] The module may include one or more interface circuits. In some examples, the interface circuits may include wired or wireless interfaces that are connected to a local area network (LAN), the Internet, a wide area network (WAN), or combinations thereof. The functionality of any given module of the present disclosure may be distributed among multiple modules that are connected via interface circuits. For example, multiple modules may allow load balancing. In a further example, a server (also known as remote, or cloud) module may accomplish some functionality on behalf of a client module.

[0069] The term code, as used above, may include software, firmware, and/or microcode, and may refer to programs, routines, functions, classes, data structures, and/or objects. The term shared processor circuit encompasses a single processor circuit that executes some or all code from multiple modules. The term group processor circuit encompasses a processor circuit that, in combination with additional processor circuits, executes some or all code from one or more modules. References to multiple processor circuits encompass multiple processor circuits on discrete dies, multiple processor circuits on a single die, multiple cores of a single processor circuit, multiple threads of a single processor circuit, or a combination of the above. The term shared memory circuit encompasses a single memory circuit that stores some or all code from multiple modules. The term group memory circuit encompasses a memory circuit that, in combination with additional memories, stores some or all code from one or more modules.

[0070] The term memory circuit is a subset of the term computer-readable medium. The term computer-readable medium, as used herein, does not encompass transitory electrical or electromagnetic signals propagating through a medium (such as on a carrier wave); the term computer-readable medium may therefore be considered tangible and non-transitory. Non-limiting examples of a non-transitory, tangible computer-readable medium are nonvolatile memory circuits (such as a flash memory circuit, an erasable programmable read-only memory circuit, or a mask read-only memory circuit), volatile memory circuits (such as a static random access memory circuit or a dynamic random access memory circuit), magnetic storage media (such as an analog or digital magnetic

tape or a hard disk drive), and optical storage media (such as a CD, a DVD, or a Blu-ray Disc).

[0071] The apparatuses and methods described in this application may be partially or fully implemented by a special purpose computer created by configuring a general purpose computer to execute one or more particular functions embodied in computer programs. The functional blocks, flowchart components, and other elements described above serve as software specifications, which can be translated into the computer programs by the routine work of a skilled technician or programmer.

[0072] The computer programs include processor-executable instructions that are stored on at least one non-transitory, tangible computer-readable medium. The computer programs may also include or rely on stored data. The computer programs may encompass a basic input/output system (BIOS) that interacts with hardware of the special purpose computer, device drivers that interact with particular devices of the special purpose computer, one or more operating systems, user applications, background services, background applications, etc.

[0073] The computer programs may include: (i) descriptive text to be parsed, such as HTML (hypertext markup language) or XML (extensible markup language), (ii) assembly code, (iii) object code generated from source code by a compiler, (iv) source code for execution by an interpreter, (v) source code for compilation and execution by a just-in-time compiler, etc. As examples only, source code may be written using syntax from languages including C, C++, C#, Objective C, Haskell, Go, SQL, R, Lisp, Java®, Fortran, Perl, Pascal, Curl, OCaml, Javascript®, HTML5, Ada, ASP (active server pages), PHP, Scala, Eiffel, Smalltalk, Erlang, Ruby, Flash®, Visual Basic®, Lua, and Python®.

[0074] None of the elements recited in the claims are intended to be a means-plus-function element within the meaning of 35 U.S.C. §112(f) unless an element is expressly recited using the phrase “means for,” or in the case of a method claim using the phrases “operation for” or “step for.”

[0075] The foregoing description of the embodiments has been provided for purposes of illustration and description. It is not intended to be exhaustive or

to limit the disclosure. Individual elements or features of a particular embodiment are generally not limited to that particular embodiment, but, where applicable, are interchangeable and can be used in a selected embodiment, even if not specifically shown or described. The same may also be varied in many ways.

- 5 Such variations are not to be regarded as a departure from the disclosure, and all such modifications are intended to be included within the scope of the disclosure.

CLAIMS

What is claimed is:

1. A waste heat recovery system comprising:

a pump;

5 a first heat exchanger disposed downstream of the pump and receiving working fluid from the pump;

an expander disposed downstream of the first heat exchanger and receiving working fluid from the first heat exchanger, the expander including an output shaft that is powered by the working fluid flowing through the expander;

10 a second heat exchanger disposed downstream of the expander and receiving working fluid from the expander, the second heat exchanger including a first inlet, a second inlet and an outlet, wherein a first fluid path through the second heat exchanger between the first inlet and the outlet has a first length, and wherein a second fluid path through the second heat exchanger between
15 the second inlet and the outlet has a second length that is shorter than the first length; and

a valve disposed upstream of the outlet of the second heat exchanger and downstream of the expander and controlling fluid flow through the first and second inlets.

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2. The waste heat recovery system of Claim 1, wherein working fluid in the first heat exchanger absorbs heat from a fluid separate from the working fluid, the fluid being selected from the group consisting of: engine exhaust gas, compressed air, and engine coolant.

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3. The waste heat recovery system of Claim 1, wherein the valve is disposed upstream of the first and second inlets.

4. The waste heat recovery system of Claim 1, wherein the second
30 fluid path includes only a portion of the first fluid path.

5. The waste heat recovery system of Claim 1, wherein the valve is movable between a first position in which working fluid is allowed to flow through the first inlet and is prevented from flowing through the second inlet, a second position in which working fluid is allowed to flow through the second inlet and is prevented from flowing through the first inlet, and a third position in which working fluid is allowed to flow through the first inlet and the second inlet.

6. The waste heat recovery system of Claim 1, further comprising a sensor disposed downstream of the second heat exchanger and upstream of the pump; and a control module in communication with the sensor and controlling operation of the valve based on data received from the sensor.

7. The waste heat recovery system of Claim 6, wherein the sensor is a temperature sensor, and wherein the control module controls the valve based on a comparison of data from the sensor and a predetermined temperature value indicative of full condensation of the working fluid exiting the outlet of the second heat exchanger.

8. The waste heat recovery system of Claim 7, wherein the first and second inlets and the outlet are formed in a vehicle panel disposed on an underbody of a vehicle such that heat from the working fluid within the second heat exchanger is transferred to air flowing between the underbody of the vehicle and a ground surface upon which the vehicle is situated.

9. The waste heat recovery system of Claim 8, wherein the vehicle panel includes a component selected from the group consisting of: a skid plate, a floor pan, a belly pan, and an under-floor aerodynamic panel.

10. The waste heat recovery system of Claim 1, wherein the second heat exchanger is integrally formed with a body panel of a vehicle.

11. A waste heat recovery system comprising:

a pump;

a first heat exchanger disposed downstream of the pump and receiving working fluid from the pump;

5 an expander disposed downstream of the first heat exchanger and receiving working fluid from the first heat exchanger, the expander including an output shaft that is powered by the working fluid flowing through the expander;

a second heat exchanger including a first fluid path having a first length and a second fluid path having a second length that is shorter than the first
10 length;

a valve disposed downstream of the expander and controlling fluid flow through the first and second fluid paths;

a sensor disposed downstream of the first and second fluid paths and upstream of the pump, the sensor measuring a parameter of the working fluid
15 indicating whether the working fluid is in a gaseous state, a liquid state or a mixture of gas and liquid; and

a control module in communication with the sensor and the valve and controlling a position of the valve based on a value of the parameter measured by the sensor.

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12. The waste heat recovery system of Claim 11, wherein the valve is disposed within the second heat exchanger between an inlet of the second heat exchanger and an outlet of the second heat exchanger.

25 13. The waste heat recovery system of Claim 11, wherein the second heat exchanger includes first inlet, a second inlet and an outlet, wherein the first fluid path extends between the first inlet and the outlet, and wherein the second fluid path extends between the second inlet and the outlet.

30 14. The waste heat recovery system of Claim 13, wherein the valve is disposed upstream of the first and second inlets.

15. The waste heat recovery system of Claim 14, wherein the valve is movable between a first position in which working fluid is allowed to flow through the first inlet and is prevented from flowing through the second inlet, a second position in which working fluid is allowed to flow through the second inlet and is prevented from flowing through the first inlet, and a third position in which working fluid is allowed to flow through the first inlet and the second inlet.

16. The waste heat recovery system of Claim 11, wherein the sensor is a temperature sensor, and wherein the control module controls the valve based on a comparison of data from the sensor and a predetermined temperature value indicative of full condensation of the working fluid exiting the second heat exchanger.

17. The waste heat recovery system of Claim 11, wherein the first and second fluid paths are formed in a vehicle panel disposed on an underbody of a vehicle such that heat from the working fluid within the second heat exchanger is transferred to air flowing between the underbody of the vehicle and a ground surface upon which the vehicle is situated.

18. The waste heat recovery system of Claim 17, wherein the vehicle panel includes a component selected from the group consisting of: a skid plate, a floor pan, a belly pan, and an under-floor aerodynamic panel.

19. The waste heat recovery system of Claim 11, wherein the second heat exchanger is integrally formed with a body panel of a vehicle.

20. A waste heat recovery system comprising:
a pump;
a first heat exchanger disposed downstream of the pump and receiving working fluid from the pump;

an expander disposed downstream of the first heat exchanger and receiving working fluid from the first heat exchanger, the expander including an output shaft that is powered by the working fluid flowing through the expander;

5 a second heat exchanger disposed downstream of the expander and receiving working fluid from the expander, the second heat exchanger formed in a vehicle panel disposed on an underbody of a vehicle such that heat from the working fluid within the second heat exchanger is transferred to air flowing between the underbody of the vehicle and a ground surface upon which the vehicle is situated.

10

21. The waste heat recovery system of Claim 20, wherein the vehicle panel includes a component selected from the group consisting of: a skid plate, a floor pan, a belly pan, and an under-floor aerodynamic panel.

15

22. The waste heat recovery system of Claim 20, wherein the second heat exchanger includes a first inlet, a second inlet and an outlet, wherein a first fluid path through the second heat exchanger between the first inlet and the outlet has a first length, and wherein a second fluid path through the second heat exchanger between the second inlet and the outlet has a second length that is shorter than the first length.

20

23. The waste heat recovery system of Claim 22, further comprising a valve disposed upstream of the outlet of the second heat exchanger and downstream of the expander and controlling fluid flow through the first and second inlets.

25

24. The waste heat recovery system of Claim 23, wherein the valve is disposed upstream of the first and second inlets.

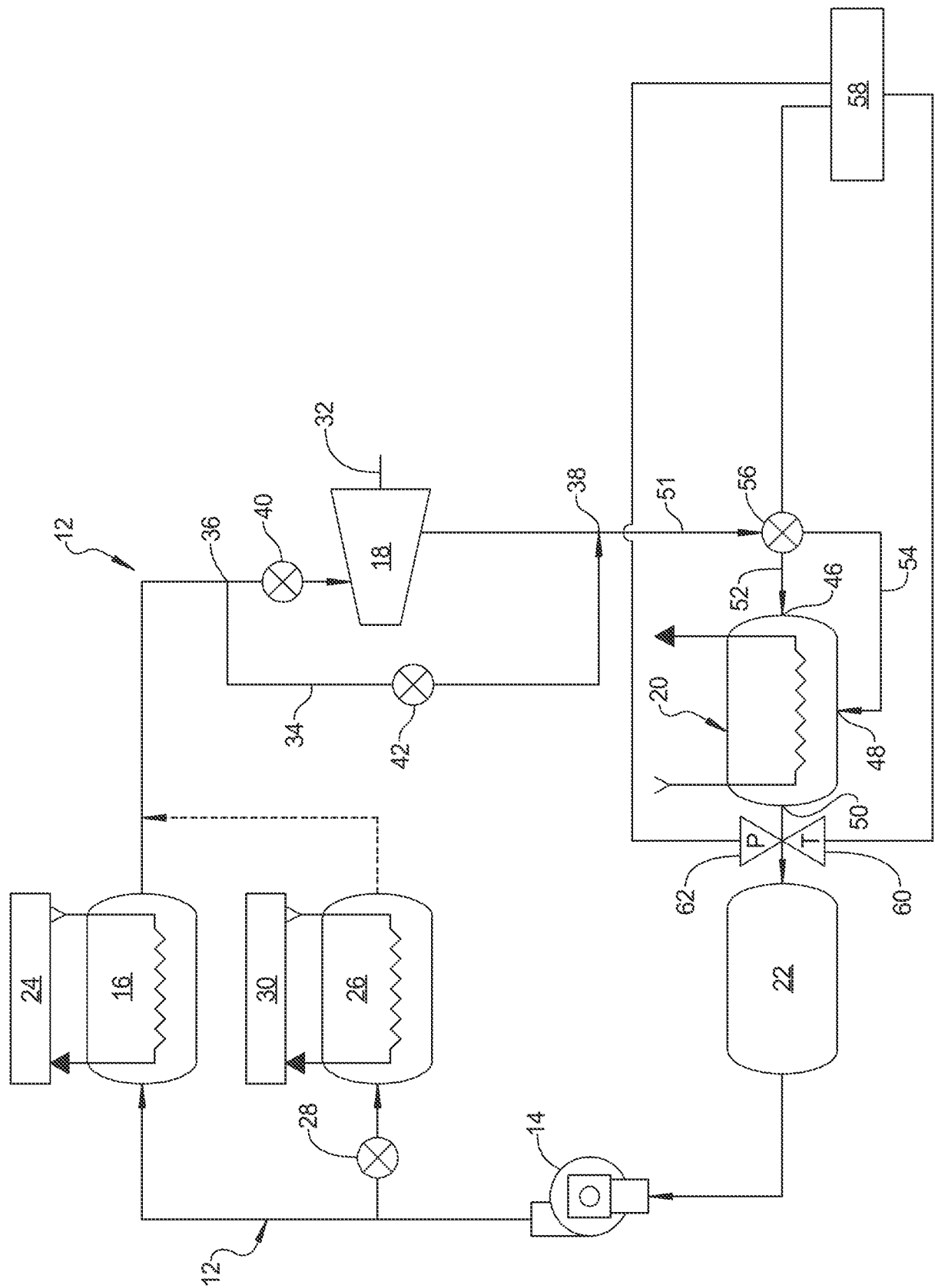
30

25. The waste heat recovery system of Claim 24, wherein the second fluid path includes only a portion of the first fluid path.

26. The waste heat recovery system of Claim 25, wherein the valve is movable between a first position in which working fluid is allowed to flow through the first inlet and is prevented from flowing through the second inlet, a second position in which working fluid is allowed to flow through the second inlet and is prevented from flowing through the first inlet, and a third position in which working fluid is allowed to flow through the first inlet and the second inlet.

27. The waste heat recovery system of Claim 26, further comprising a sensor disposed downstream of the second heat exchanger and upstream of the pump; and a control module in communication with the sensor and controlling operation of the valve based on data received from the sensor.

28. The waste heat recovery system of Claim 27, wherein the sensor is a temperature sensor, and wherein the control module controls the valve based on a comparison of data from the sensor and a predetermined temperature value indicative of full condensation of the working fluid exiting the outlet of the second heat exchanger.



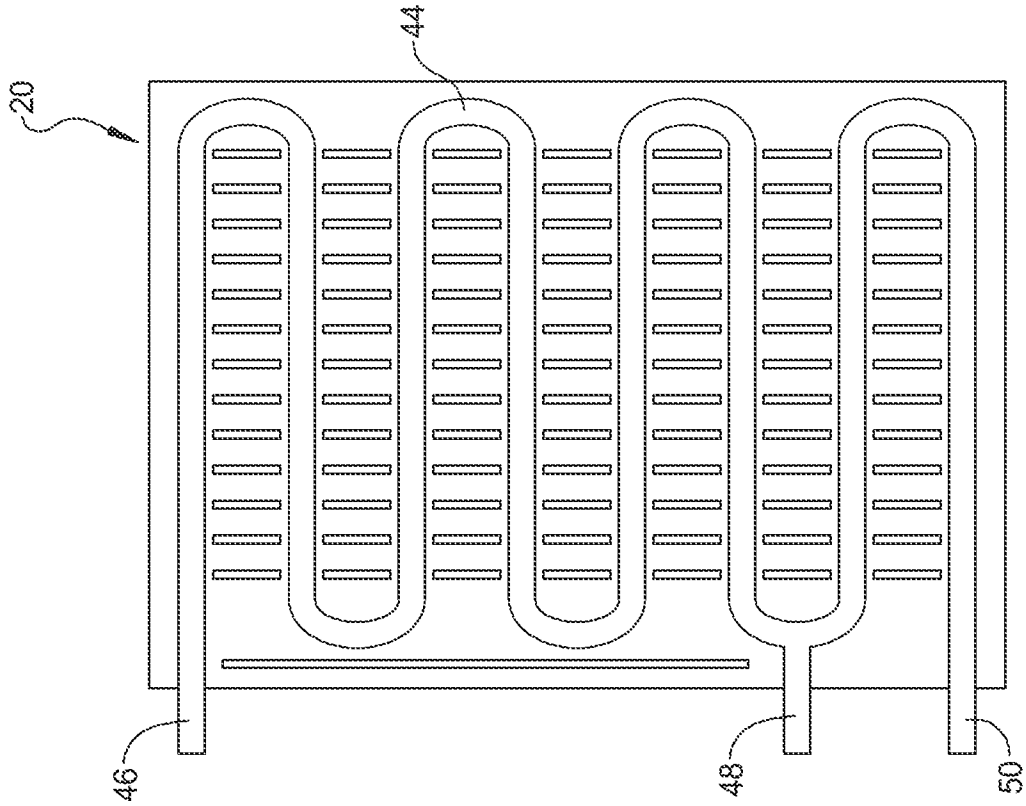


FIG 2

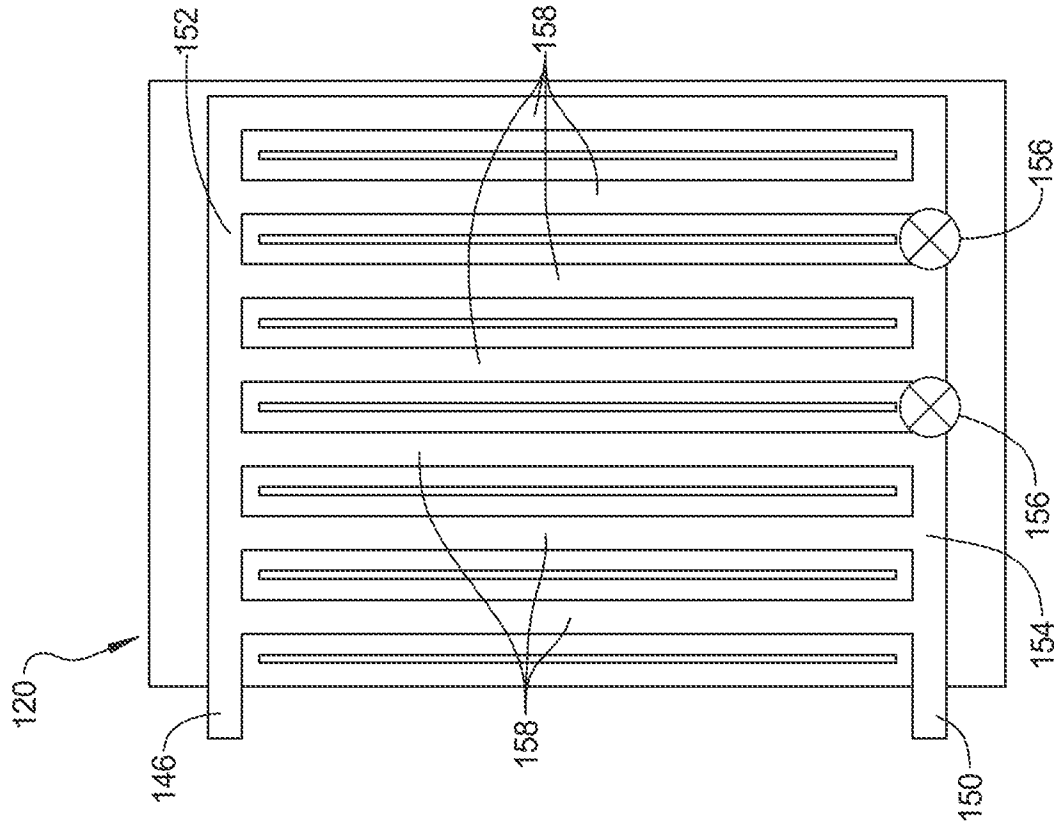


FIG 3

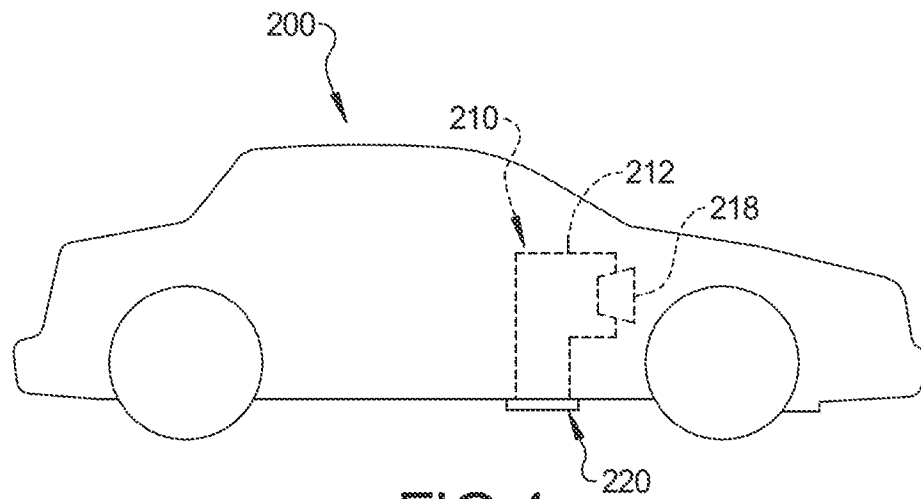


FIG 4

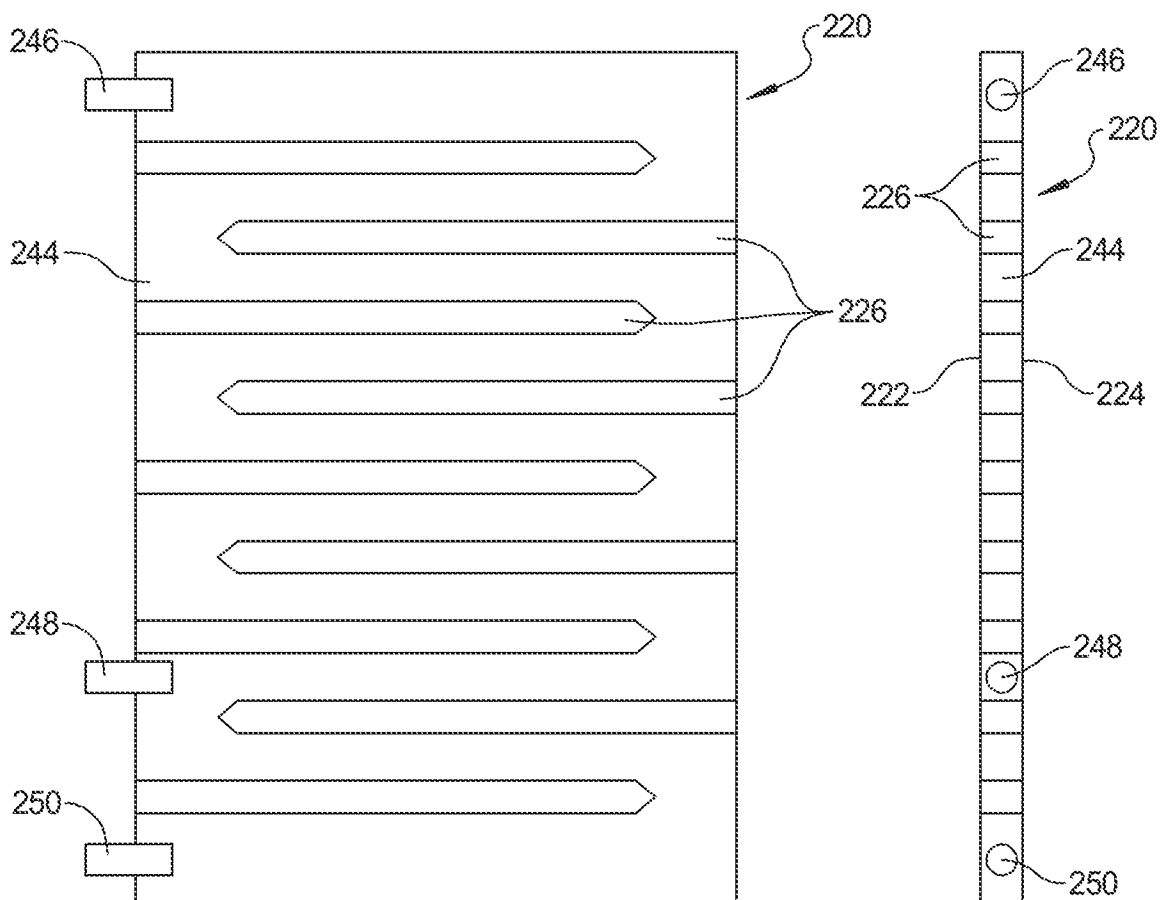


FIG 5

FIG 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2015/056919**A. CLASSIFICATION OF SUBJECT MATTER****F01K 23/02(2006.01)i, F01K 23/08(2006.01)i, F01K 23/10(2006.01)i, F02G 5/00(2006.01)i, F02G 5/02(2006.01)i, F01N 5/02(2006.01)i, F01K 13/00(2006.01)i, B60R 16/08(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F01K 23/02; F25B 41/04; F01K 13/02; F02G 3/00; F01K 7/42; F28F 9/26; F25B 1/00; F01K 23/08; F01K 23/10; F02G 5/00; F02G 5/02; F01N 5/02; F01K 13/00; B60R 16/08

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: waste heat recovery system, pump, heat exchanger, evaporator, condenser, valve, expander, inlet, outlet, control module

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013-0067910 A1 (ISHIGURO et al.) 21 March 2013 See abstract; paragraphs [0027]-[0028], [0033]-[0037], [0045]-[0046], [0077]-[0089], [0096]; claim 1; and figures 1-2, 7-9.	11-12, 16-21
Y		1-10, 13-15, 22-28
Y	US 5005351 A (ARCHER, DAVID H.) 09 April 1991 See abstract; column 2, line 60 - column 3, line 62; and figure 1.	1-10, 13-15, 22-28
A	US 6382310 B1 (SMITH, SEAN A.) 07 May 2002 See abstract; column 4, lines 35-58; and figures 1-2.	1-28
A	US 2010-0307155 A1 (KASUYA et al.) 09 December 2010 See abstract; paragraphs [0029]-[0031], [0035]-[0042]; and figure 1.	1-28
A	US 2010-0229579 A1 (KNIGHT et al.) 16 September 2010 See abstract; paragraphs [0031]-[0033]; and figures 2-4.	1-28



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

22 December 2015 (22.12.2015)

Date of mailing of the international search report

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Name and mailing address of the ISA/KR

International Application Division

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2015/056919

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2013-0067910 A1	21/03/2013	CN 103016137 A EP 2573335 A2 EP 2573335 A3 JP 2013-079641 A	03/04/2013 27/03/2013 09/10/2013 02/05/2013
US 5005351 A	09/04/1991	EP 0444892 A2 JP 04-217786 A	04/09/1991 07/08/1992
US 6382310 B1	07/05/2002	AU 2001-77079 A1 WO 02-14767 A2 WO 02-14767 A3	25/02/2002 21/02/2002 23/05/2002
US 2010-0307155 A1	09/12/2010	EP 2249017 A1 EP 2249017 A4 EP 2249017 B1 JP 5281587 B2 WO 2009-101977 A1	10/11/2010 23/03/2011 27/03/2013 04/09/2013 20/08/2009
US 2010-0229579 A1	16/09/2010	BR PI0519461A2 CA 2523965 A1 CA 2523965 C CA 2550277 A1 CA 2591236 A1 EP 1831610 A1 MX 2007007795 A US 2004-0089002 A1 US 2004-0089015 A1 US 2005-0022541 A1 US 2005-0115254 A1 US 2006-0086115 A1 US 2006-0137371 A1 US 2006-0288713 A1 US 2007-0175227 A1 US 2009-0064711 A1 US 2011-0167846 A1 US 7062930 B2 US 7219505 B2 US 7434415 B2 US 7694527 B2 US 7726140 B2 US 7770411 B2 US 7845185 B2 WO 2006-071858 A1	27/01/2009 22/04/2006 30/09/2008 23/12/2006 06/07/2006 12/09/2007 23/08/2007 13/05/2004 13/05/2004 03/02/2005 02/06/2005 27/04/2006 29/06/2006 28/12/2006 02/08/2007 12/03/2009 14/07/2011 20/06/2006 22/05/2007 14/10/2008 13/04/2010 01/06/2010 10/08/2010 07/12/2010 06/07/2006