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(54) **Fire extinguishing system for an organic rankine cycle hydrocarbon evaporator**

(57) The present invention provides an organic Rankine cycle energy recovery system comprising features which provide for fire suppression and/or ignition suppression in the event of an unintentional release of a flammable component of the system, for example a flammable working fluid such as cyclopentane, into a part of

the of the system in which the prevailing temperature is higher than the autoignition temperature of the flammable component. In one embodiment the organic Rankine cycle energy recovery system comprises an inert gas source disposed upstream of a hydrocarbon evaporator and is configured to purge the hydrocarbon evaporator with an inert gas on detection of a leak thereby.

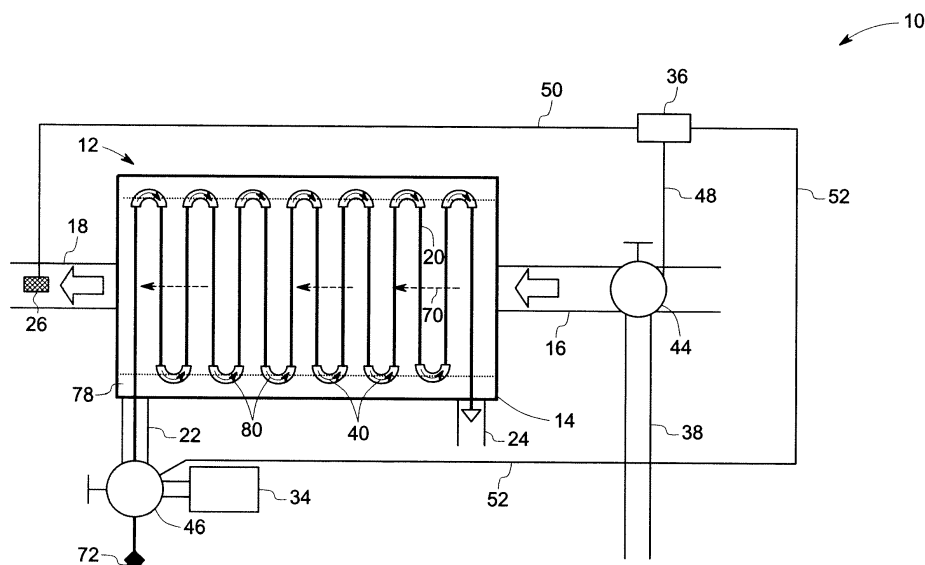


FIG. 2

Description

BACKGROUND

[0001] The invention relates generally to an organic Rankine cycle energy recovery system, and more particularly to an evaporator apparatus and method for energy recovery employing the same.

[0002] So called "waste heat" generated by a large number of human activities represents a valuable and often underutilized resource. Sources of waste heat include hot combustion exhaust gases of various types including flue gas. Industrial turbomachinery such as turbines frequently create large amounts of recoverable waste heat in the form of hot gaseous exhaust streams.

[0003] Organic Rankine cycle energy recovery systems have been deployed as retrofits, to capture waste heat from, for example, a turbine's hot gas stream and convert the heat recovered into desirable power output. In an organic Rankine cycle, heat is transmitted to an organic fluid, typically called the working fluid, in a closed loop. The working fluid is heated by thermal contact with the waste heat and is vaporized and then expanded through a work extraction device such as a turbine during which expansion kinetic energy is transferred from the expanding gaseous working fluid to the moving components of the turbine. Mechanical energy is generated thereby which can be converted into electrical energy, for example. The gaseous working fluid having transferred a portion of its energy content to the turbine is then condensed into a liquid state and returned to the heating stages of the closed loop for reuse.

[0004] A working fluid used in such organic Rankine cycle energy recovery systems is typically a low boiling hydrocarbon such as cyclopentane. As such, the working fluid is subject to degradation at high temperatures. In a variety of applications the organic Rankine cycle energy recovery system relies on a heat source gas having an initial temperature on the order of 500 degrees Celsius which is brought into thermal contact with the working fluid across a heat transmissive barrier, such as the wall of a heat exchange tube containing the working fluid.

[0005] Thus, the use of an organic Rankine cycle energy recovery system to recover waste heat from, for example, a hot exhaust gas stream produced by a gas turbine, is faced with the dilemma that the temperature of the exhaust gas stream exceeds the autoignition temperature of the working fluid. Under such conditions, direct contact of the working fluid with the exhaust gas stream caused by a failure of a component of the organic Rankine cycle energy recovery system could produce an elevated risk of fire and/or explosion.

[0006] Therefore, there is a need to provide improved organic Rankine cycle systems which contemplate such system failures and provide appropriate measures for risk reduction.

BRIEF DESCRIPTION

[0007] In one aspect, the present invention provides an organic Rankine cycle energy recovery system comprising: (a) an evaporator apparatus comprising a housing, a heat source gas inlet, a heat source gas outlet, a working fluid inlet, a working fluid outlet, and a heat exchange tube disposed within the housing and in fluid communication with the working fluid inlet and the working fluid outlet; (b) a detector capable of sensing the working fluid or a combustion by-product thereof; (c) a work extraction device; (d) a condenser; (e) a pump; (f) an inert gas source disposed upstream of the evaporator; (g) a controller configured to receive an output from the detector; and (h) a heat source gas by-pass; wherein the controller is configured to actuate the inert gas source, and wherein the controller is configured to divert a heat source gas to the heat source gas by-pass, and wherein the controller is configured to prevent introduction of a working fluid into the evaporator.

[0008] In another aspect, the present invention provides a method of energy recovery from an organic Rankine cycle system comprising: (i) introducing a heat source gas into an evaporator apparatus comprising a heat exchange tube containing a working fluid; (ii) transferring heat from the heat source gas to the working fluid to provide a heated working fluid; (iii) transferring energy from the heated working fluid to a work extraction device located outside of the evaporator apparatus; (iv) returning the working fluid to the evaporator apparatus; wherein the method is carried out in an organic Rankine cycle energy recovery system configured to detect the working fluid or a combustion by-product thereof and to generate a signal in response to the detection, and wherein the organic Rankine cycle energy recovery system is configured to receive the signal from the detector at a controller, and wherein the controller is configured to actuate an inert gas source upstream of the evaporator in response to the signal, and wherein the controller is configured to divert the heat source gas into a heat source gas by-pass in response to the signal, and wherein the controller is configured to prevent introduction of a working fluid into the evaporator apparatus in response to the signal.

[0009] In yet another aspect, the present invention provides an evaporator apparatus for use in an organic Rankine cycle energy recovery system, comprising: a housing, a heat source gas inlet, a heat source gas outlet, a working fluid inlet, a working fluid outlet, a heat exchange tube disposed within the housing and in fluid communication with the working fluid inlet and the working fluid outlet, and a detector capable of sensing the working fluid, or a combustion by-product thereof, wherein the working fluid inlet is coupled to a valve configured to be switchable between a working fluid source and an inert gas source.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

[0011] Fig. 1 is a schematic illustration of an organic Rankine cycle energy recovery system in accordance with an embodiment of the invention.

[0012] Fig. 2 is a schematic illustration of an organic Rankine cycle energy recovery system in accordance with an embodiment of the invention.

[0013] Fig. 3 is a flow chart illustrating the operation of an organic Rankine cycle energy recovery system in response to detection of a fugitive emission of the working fluid in accordance with an embodiment of the invention.

DETAILED DESCRIPTION

[0014] In the following specification and the claims, which follow, reference will be made to a number of terms, which shall be defined to have the following meanings.

[0015] The singular forms "a", "an" and "the" include plural referents unless the context clearly dictates otherwise.

[0016] "Optional" or "optionally" means that the subsequently described event or circumstance may or may not occur, and that the description includes instances where the event occurs and instances where it does not.

[0017] It is also understood that terms such as "top," "bottom," "outward," "inward," and the like are words of convenience and are not to be construed as limiting terms. Furthermore, whenever a particular feature of the invention is said to comprise or consist of at least one of a number of elements of a group and combinations thereof, it is understood that the feature may comprise or consist of any of the elements of the group, either individually or in combination with any of the other elements of that group.

[0018] Approximating language, as used herein throughout the specification and claims, may be applied to modify any quantitative representation that could permissibly vary without resulting in a change in the basic function to which it is related. Accordingly, a value modified by a term or terms, such as "about", is not to be limited to the precise value specified. In some instances, the approximating language may correspond to the precision of an instrument for measuring the value. Similarly, "free" may be used in combination with a term, and may include an insubstantial number, or trace amounts, while still being considered free of the modified term.

[0019] As noted, in one embodiment the present invention provides an organic Rankine cycle energy recovery system comprising: (a) an evaporator apparatus comprising a housing, a heat source gas inlet, a heat source gas outlet, a working fluid inlet, a working fluid outlet, and

a heat exchange tube disposed within the housing and in fluid communication with the working fluid inlet and the working fluid outlet; (b) a detector capable of sensing the working fluid or a combustion by-product thereof; (c) a work extraction device; (d) a condenser; (e) a pump; (f) an inert gas source disposed upstream of the evaporator; (g) a controller configured to receive an output from the detector; and (h) a heat source gas by-pass; wherein the controller is configured to actuate the inert gas source, and wherein the controller is configured to divert a heat source gas to the heat source gas by-pass, and wherein the controller is configured to prevent introduction of a working fluid into the evaporator.

[0020] Fig. 1 is a schematic illustration of an organic Rankine cycle energy recovery system 10 according to one embodiment of the invention. The system includes an evaporator apparatus 12 coupled to a heat source (not shown) that provides a heat source gas 17 (See Fig. 2). In various embodiments of the invention, the heat source may be any heat source which may be used to produce a gas stream susceptible to introduction into the evaporator apparatus via the heat source gas inlet. For example, the heat source may be a gas turbine, the exhaust from which may be used as the heat source gas. Other heat sources include exhaust gas producing equipment used in residential, commercial, and industrial settings; for example clothes dryers, air conditioning units, refrigeration units, and gas streams produced during fuel combustion, for example flue gases.

[0021] Referring again to Fig. 1, the evaporator apparatus 12 includes a housing 14, a heat source gas inlet 16, heat source gas outlet 18, a working fluid inlet 22, and a working fluid outlet 24. The housing defines a heat source gas flow path from said heat source gas inlet to said heat source gas outlet. In one embodiment, the heat source gas flow path is essentially the entire interior of the evaporator apparatus defined by the housing wall and space within the interior of the evaporator apparatus not occupied by the heat exchange tube 20. The heat exchange tube 20 is disposed within the housing and in fluid communication with the working fluid inlet and the working fluid outlet. In one embodiment, the heat exchange tube 20 is disposed within the heat source gas flow path. In another embodiment, the heat exchange tube 20 is not disposed within the heat source gas flow path.

[0022] In the embodiments shown in Fig. 1 and Fig 2, the heat exchange tube 20 is represented as a single tube disposed between a single working fluid inlet 22 and a single working fluid outlet 24. As used herein, however, the expression "a heat exchange tube disposed within the housing and in fluid communication with the working fluid inlet and the working fluid outlet" may include a plurality of heat exchange tubes disposed within the housing of a evaporator apparatus and in fluid communication with one or more working fluid inlets and one or more working fluid outlets.

[0023] The heat exchange tube 20 is configured to ac-

commodate an organic Rankine cycle working fluid 40 (See Fig. 2). As noted, in the embodiment shown in Fig. 1, the evaporator apparatus 12 is coupled to a heat source (not shown) which is configured to provide the heat source gas 17 (See Fig. 2) that enters the evaporator apparatus 12 via heat source gas inlet 16 and contacts the heat exchange tube 20 along the heat source gas flow path 70 (See Fig. 2) to facilitate heat exchange between the working fluid 40 and the heat source gas in a manner that does not overheat the working fluid 40. In one embodiment, the working fluid 40 travels along the working fluid flow path (not shown) defined by the interior of the heat exchange tube 20. In one embodiment, the temperature of the heat source gas is in a range from about 375 degrees Celsius to about 450 degrees Celsius.

[0024] As noted, the working fluid 40 may, in one embodiment, be a hydrocarbon. Non-limiting examples of hydrocarbons include cyclopentane, n-pentane, isopentane, propane, butane, n-hexane and cyclohexane. In another embodiment, the working fluid 40 can be a mixture of two or more hydrocarbons. In one embodiment, the working fluid 40 is a binary fluid such as, for example, cyclohexane-propane, cyclohexane-butane, cyclopentane-isopentane, cyclopentane-butane, or cyclopentane-cyclohexane mixtures. In yet another embodiment, the working fluid 40 is a hydrocarbon selected from the group consisting of cyclopentane, cyclohexane, and mixtures thereof. In another embodiment, the working fluid 40 is a hydrocarbon selected from the group consisting of cyclopentane and cyclohexane.

[0025] The organic Rankine cycle energy recovery system provided by the present invention comprises a detector 26, the detector being capable of detecting even minute quantities of the working fluid or a combustion by-product or byproducts of the working fluid at one or more locations within the system. For the purposes of this disclosure, light generated by combustion of the working fluid is considered to be a by-product of combustion and in various embodiments of the invention the detector is configured to detect such light within the evaporator apparatus. Thus, in one embodiment, the detector is disposed within the evaporator apparatus 12. In an alternate embodiment, the detector is disposed in a portion of the organic Rankine cycle energy recovery system which is downstream of the evaporator apparatus 12. For example in piping configured to remove heat source gas from the evaporator apparatus downstream of the heat source gas outlet. Those skilled in the art may conceive of other suitable locations where the detector 26 may be located, based on the varying sensor and organic Rankine cycle system design.

[0026] In one embodiment, the detector 26 is selected from the group consisting of photo-detectors, metal oxide sensors, solid-state sensors, infrared spectrometric detectors, ultraviolet-visible spectrometric detectors, temperature sensors such as thermocouples, optical pyrometers, fiber optic sensors, resistive thermal devices for measuring gas temperature, and flame detectors. In one

embodiment, the detector 26 is a photo-detector capable of sensing light generated during combustion of the working fluid. In an alternate embodiment, the detector comprises an infrared spectrometric detector.

[0027] The organic Rankine cycle energy recovery system of the present invention includes an inert gas source 34 which is upstream of the evaporator. When used in reference to the inert gas source, the expression "upstream of the evaporator" means that the inert gas source is configured such that when the inert gas source is allowed to enter the evaporator apparatus it does so via the working fluid inlet, for example working fluid inlet 24. Typically, the inert gas source 34 and the working fluid return line designated element 72 in Fig. 2 are both coupled to a multi-way valve 46 which is linked to a controller 36. The controller exercises control over the status of the multi-way valve 46 such that when the multi-way valve is open with respect to fluid flow from the inert gas source 34 into the interior of heat exchange tube 20, the multi-way valve 46 is closed with respect to the flow of working fluid 40 (Fig. 2) into the interior of heat exchange tube 20. In one embodiment, the multi-way valve 46 is a two-way valve. Thus, the organic Rankine cycle energy recovery system provided by the present invention is configured such that flow of the working fluid into the evaporator apparatus and fluid flow from the inert gas source are mutually exclusive. In various embodiments, because of this mutual exclusion principle and the fact that the controller exercises control over the status of the multi-way valve 46, the controller is said to be configured to prevent introduction of a working fluid into the evaporator.

[0028] The inert gas source may comprise any fire suppressive and/or ignition suppressive fluid and need not fall within the strict definition of the term "inert gas". The role of the inert gas source is to displace the working fluid in the evaporator apparatus in the event of a failure within the system resulting in the fugitive emission of the working fluid. Where, for example, the fugitive emission of the working fluid is caused by the presence of a pinhole in the heat exchange tube 20 inside the evaporator apparatus, a detector located within the evaporator apparatus or downstream from it detects the working fluid or a combustion by-product of the working fluid and generates a signal which is received by the controller. The controller, among other things, directs the multi-way valve 46 to close with respect to the flow of working fluid into the evaporator apparatus and opens with respect to the flow of a fire suppressive and/or ignition suppressive fluid from the inert gas source. Thus, in one embodiment, the controller is said to be configured to "actuate" the inert gas source, meaning simply that the controller can initiate the flow of fluid from the inert gas source into the evaporator apparatus.

[0029] In one embodiment, the inert gas source 34 comprises an inert gas selected from the group consisting of nitrogen, argon, carbon dioxide and combinations thereof. In an alternate embodiment, the inert gas source comprises a suppressive and/or ignition suppressive flu-

id comprising a halocarbon, for example heptafluoropropane (See FM-200®). In one embodiment, the inert gas source consists essentially of nitrogen.

[0030] As noted, the organic Rankine cycle energy recovery system includes a controller 36 configured to receive an output signal from the detector 26, the output signal being generated as a result of the sensing by the detector of the working fluid or a combustion by-product of the working fluid indicative of a fugitive emission of the working fluid. The controller may act to control various system components in the event of its receiving an output signal from the detector, for example: heat source gas inlet valve 44 which may be controlled to direct the heat source gas either to the evaporator apparatus 12 or a heat source gas by-pass 38; and the multi-way valve 46, also referred to herein as the working fluid inlet valve 46. In one embodiment, during operation of the organic Rankine cycle energy recovery system 10, when the detector 26 senses the presence of at one of the working fluid 40 or combustion by-product thereof in the evaporator apparatus 12 outside the heat exchange tube 20, a signal is sent to the controller 36. The controller may communicate with the detector and various other system components by wireless or hardwired communications links, or by a combination of wireless and hardwired communications links. In one embodiment, the communications links are configured to transmit electrical signals. In an alternate embodiment, the communications links are configured to transmit optical signals. In yet another embodiment, the communications links may communicate any one of an electrical signal and an optical signal. In one embodiment, the communications links are configured to transmit acoustic signals. In one embodiment, the controller 36 is coupled to the detector 26 via communications link 50, to the heat source gas inlet valve 44 via communications link 48, and to the working fluid inlet valve 46 via communications link 52.

[0031] As noted, the controller 36 is configured to actuate the inert gas source 34 by switching valve 46 and commencing flow of inert fluid (a fire suppressive and/or ignition suppressive fluid) from the inert gas source 34 through the working fluid inlet 22, and thereby displacing any working fluid present within the heat exchange tube 20 inside the evaporator apparatus. Displaced working fluid may be relocated to a portion of the organic Rankine cycle energy recovery system located outside of the evaporator apparatus where it may be safely contained until needed, for example a working fluid holding tank (not shown). In addition, actuation of the inert gas source 34 is carried out such that further introduction of the working fluid into the evaporator apparatus via the working fluid inlet is prevented.

[0032] As noted, the controller 36 is configured to divert the heat source gas to a heat source gas by-pass 38. This permits the evaporator apparatus to be cooled rapidly in the event of a fugitive emission of the working fluid within the evaporator apparatus.

[0033] During operation of the organic Rankine cycle

energy recovery system, heat from the heat source gas is transferred to the working fluid 40 contained within the heat exchange tube 20 to generate a heated working fluid (also sometimes referred to as "working fluid vapor").

5 The temperature of the heat source gas entering the evaporator apparatus may vary depending on its source and the distance between the heat source and the evaporator apparatus. In one embodiment, the temperature of the heat source gas entering the evaporator apparatus is in a range from about 350 degrees Celsius to about 600 degrees Celsius. In one embodiment, the temperature of heated working fluid which emerges from the evaporator apparatus via the working fluid outlet is in a range from about 150 degrees Celsius to about 300 degrees Celsius. In one embodiment, the heated working fluid has a pressure in a range from about 20 to about 30 bar.

[0034] The heated working fluid vapor may be passed through an expander 28 to drive a work extraction device (not shown). In an exemplary embodiment, the expander may be a radial type expander, an axial type expander, an impulse type expander, or a high temperature screw type expander. After passing through the expander 28, the working fluid vapor having transferred a portion of its energy to the expander and now at relatively lower pressure and lower temperature is passed through a condenser 30 where it is condensed into the liquid state working fluid 40, which is then pumped via pump 32 back to the evaporator apparatus 12 via working fluid inlet 22. In another embodiment, after passing through the expander 28, the working fluid vapor at a relatively lower pressure and lower temperature prior to entering the condenser, may be passed through a recuperator (not shown), which may function as a heat exchange unit. In one example, the condensed working fluid may be supplied to the evaporator apparatus 12 at a pressure of about 20 bar and a temperature of about 50 degrees Celsius. The evaporator apparatus, work extraction device, condenser and pump are configured to operate with the working fluid constrained in a closed loop.

[0035] Referring to Fig. 2, the figure represents a portion of an organic Rankine cycle energy recovery system 10 comprising an evaporator apparatus 12 and other system components in accordance with an exemplary embodiment of the present invention. The evaporator apparatus 12 includes a housing 14, a heat source gas inlet 16, and a heat source gas outlet 18. In the illustrated embodiment, the heat exchange tube 20 is disposed inside the evaporator apparatus within heat source gas flow path 70. As shown in Fig. 2 the heat source gas flow path 70 is essentially the entire interior of the evaporator apparatus 12 defined by the housing wall 78 and the space within the interior of the evaporator apparatus 12 not occupied by heat exchange tube 20. In the embodiment shown in Fig. 2, the heat exchange tube 20 is secured within the evaporator apparatus housing 14 by embedded portions 80 of the heat exchange tube 20 within the housing wall 78. A detector 26 capable of sensing

the working fluid or a combustion product thereof is located downstream of the heat source gas outlet 18. A heat source gas by-pass 38 is coupled via a heat source gas inlet valve 44 to the heat source gas inlet 16. Valve 44 may be switched to direct the flow of heat source gas to either the evaporator apparatus or to the heat source gas by-pass. The working fluid inlet 22 is coupled to a working fluid inlet valve 46, which is further coupled to an inert gas source 34. In the illustrated featured in Fig. 2 the heat source gas inlet valve 44, the working fluid inlet valve 46 and the detector 26 are coupled to a controller 36 via communications links 48, 52 and 50 respectively.

[0036] As noted, in aspect, the present invention provides a method of energy recovery from an organic Rankine cycle system. In one embodiment, the method comprises (i) introducing a heat source gas into an evaporator apparatus comprising a heat exchange tube containing a working fluid; (ii) transferring heat from the heat source gas to the working fluid to provide a heated working fluid; (iii) transferring energy from the heated working fluid to a work extraction device located outside of the evaporator apparatus; and (iv) returning the working fluid to the evaporator apparatus. The method is carried out in an organic Rankine cycle energy recovery system configured to detect the working fluid or a combustion by-product thereof. Moreover, the organic Rankine cycle energy recovery system is configured to generate a signal in response to the detection of the working fluid or the combustion by-product thereof. The organic Rankine cycle energy recovery system is configured to receive the signal from the detector at a controller, and the controller is configured to actuate an inert gas source upstream of the evaporator in response the signal. In addition, the controller is configured to divert the heat source gas into a heat source gas by-pass and away from the evaporator apparatus in response the signal, and to prevent the introduction of additional working fluid to the evaporator apparatus in response the signal.

[0037] Referring to Fig. 3, the figure shows a flow chart 100 illustrating a method of operating an organic Rankine cycle energy recovery system in accordance with an embodiment of the present invention. In a first method step 108, a detector 26 detects the presence of at least one of the working fluid 40 or a combustion by-product thereof and generates a signal in response thereto and transmits the signal to a controller 36. In a second method step 110 the controller initiates an emergency shutdown protocol of the organic Rankine cycle energy recovery system comprising steps 112-122. In a first series of method steps 112-118, the controller directs the pump to stop transporting working fluid to the evaporator apparatus (112), directs the gradual opening of the expander by-pass 54 (See Fig. 1) (114), directs the heat source gas to be diverted into the heat source gas by-pass and away from the evaporator apparatus (116), and directs fans associated with the condenser (fans not shown in Fig. 1) to be set to full power in order to maximize the heat re-

moval capacity of the condenser (118). Method steps 112-118 may be carried out in any order depending on circumstances. Following method steps 112-118, the controller in method step 120 actuates the inert gas source to begin purging the heat exchange tube or tubes within the evaporator apparatus of working fluid. Purged working fluid may be stored at a suitable, secure location. In method step 122, the flow of fire suppressive and/or ignition suppressive fluid from the inert gas source may be terminated. In an alternate embodiment, the flow of the fire suppressive and/or ignition suppressive fluid from the inert gas source may be continued in order to maintain an inert atmosphere within various components of the system. For example, in the event of a significant failure of the heat exchange tube or tubes within the evaporator apparatus, an inert atmosphere may be maintained within the heat source gas flow path within the evaporator apparatus and downstream thereof by continuing the flow of the fire suppressive and/or ignition suppressive fluid from the inert gas source.

[0038] This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

[0039] Various aspects and embodiments of the present invention are defined by the following numbered clauses:

1. An organic Rankine cycle energy recovery system comprising:

(a) an evaporator apparatus comprising a housing, a heat source gas inlet, a heat source gas outlet, a working fluid inlet, a working fluid outlet, and a heat exchange tube disposed within the housing and in fluid communication with the working fluid inlet and the working fluid outlet;

(b) a detector capable of sensing the working fluid or a combustion by-product thereof;

(c) a work extraction device;

(d) a condenser;

(e) a pump;

(f) an inert gas source disposed upstream of the evaporator;

(g) a controller configured to receive an output from the detector; and

(h) a heat source gas by-pass;
wherein the controller is configured to actuate the inert gas source,
and wherein the controller is configured to divert a heat source gas to the heat source gas by-pass,
and wherein the controller is configured to prevent introduction of a working fluid into the evaporator.

2. The energy recovery system of clause 1, wherein the detector is selected from the group consisting of gas sensors, photo-detectors, solid-state sensors, infrared spectrometric detectors, ultraviolet detectors, temperature sensors, and flame sensors.

3. The energy recovery system of clause 1 or clause 2, wherein the detector is disposed within the evaporator housing.

4. The energy recovery system of any preceding clause, wherein the detector is disposed outside of the evaporator housing.

5. The energy recovery system of any preceding clause, wherein the detector is disposed downstream of the evaporator.

6. The energy recovery system of any preceding clause, wherein the inert gas source comprises an inert gas selected from the group consisting of nitrogen, argon, carbon dioxide, and combinations of two or more of the foregoing gases.

7. The energy recovery system of any preceding clause, wherein the work extraction device comprises a turbine.

8. The energy recovery system according to clause 7, wherein said turbine is configured to produce electrical energy.

9. A method of energy recovery from an organic Rankine cycle system comprising:

- (i) introducing a heat source gas into an evaporator apparatus comprising a heat exchange tube containing a working fluid;
- (ii) transferring heat from the heat source gas to the working fluid to provide a heated working fluid;
- (iii) transferring energy from the heated working fluid to a work extraction device located outside of the evaporator apparatus; and
- (iv) returning the working fluid to the evaporator

apparatus;

wherein the method is carried out in an organic Rankine cycle energy recovery system configured to detect the working fluid or a combustion by-product thereof and to generate a signal in response to the detection,
and wherein the organic Rankine cycle energy recovery system is configured to receive the signal from the detector at a controller,
and wherein the controller is configured to actuate an inert gas source upstream of the evaporator in response the signal,
and wherein the controller is configured to divert the heat source gas into a heat source gas by-pass in response the signal,
and wherein the controller is configured to prevent introduction of a working fluid into the evaporator apparatus in response the signal.

10. The method according to clause 9, wherein the organic Rankine cycle energy recovery system comprises:

(a) an evaporator apparatus comprising a housing, a heat source gas inlet, a heat source gas outlet, a working fluid inlet, a working fluid outlet, and a heat exchange tube disposed within the housing and in fluid communication with the working fluid inlet and the working fluid outlet;

(b) a detector capable of sensing the working fluid or a combustion by-product thereof;

(c) a work extraction device;

(d) a condenser;

(e) a pump;

(f) an inert gas source disposed upstream of the evaporator apparatus;

(g) a controller configured to receive an output from the detector; and

(h) a heat source gas by-pass
wherein the controller is configured to actuate the inert gas source,
and wherein the controller is configured to divert a heat source gas to the heat source gas by-pass,
and wherein the controller is configured to prevent introduction of a working fluid into the evaporator.

11. The method according to clause 9 or clause 10, wherein the detector is selected from the group consisting of gas sensors, photo-detectors, solid-state

sensors, infrared spectrometric detectors, ultraviolet detectors, temperature sensors, and flame sensors.

12. The method according to any of clauses 9 to 11, wherein the inert gas source comprises an inert gas selected from the group consisting of nitrogen, argon, carbon dioxide and combinations thereof. 5

13. The method according to any of clauses 9 to 12, wherein the working fluid is a hydrocarbon. 10

14. The method according to any of clauses 9 to 13, wherein the working fluid is selected from the group consisting of cyclopentane and cyclohexane. 15

15. The method according to any of clauses 9 to 14, wherein the heat source gas contains oxygen.

16. The method according to any of clauses 9 to 15, wherein the heat source gas is flue gas. 20

17. The method according to any of clauses 9 to 16, wherein the inert gas source comprises at least one inert gas selected from the group consisting of nitrogen, argon, and carbon dioxide. 25

18. The method according to any of clauses 9 to 17, wherein the detector is disposed within the evaporator housing. 30

19. The method according to any of clauses 9 to 18, wherein the detector is disposed downstream of the evaporator.

20. An evaporator apparatus for use in an organic Rankine cycle energy recovery system, comprising: 35

a housing, a heat source gas inlet, a heat source gas outlet, a working fluid inlet, a working fluid outlet, a heat exchange tube disposed within the housing and in fluid communication with the working fluid inlet and the working fluid outlet, and a detector capable of sensing the working fluid, or a combustion by-product thereof, wherein the working fluid inlet is coupled to a valve configured to be switchable between a working fluid source and an inert gas source. 40 45

Claims 50

1. An organic Rankine cycle energy recovery system comprising:

(a) an evaporator apparatus (12) comprising a housing (14), a heat source gas inlet (16), a heat source gas outlet (18), a working fluid inlet (22), a working fluid outlet (24), and a heat exchange 55

tube (20) disposed within the housing (14) and in fluid communication with the working fluid inlet (22) and the working fluid outlet (24);

(b) a detector (26) capable of sensing the working fluid (40) or a combustion by-product thereof;

(c) a work extraction device (42);

(d) a condenser (30);

(e) a pump (32);

(f) an inert gas source (34) disposed upstream of the evaporator (12);

(g) a controller (36) configured to receive an output from the detector (26); and

(h) a heat source gas by-pass (38);

wherein the controller (36) is configured to actuate the inert gas source (34),

and wherein the controller (36) is configured to divert a heat source gas to the heat source gas by-pass (38),

and wherein the controller (36) is configured to prevent introduction of a working fluid (40) into the evaporator (12).

2. The energy recovery system of claim 1, wherein the detector (26) is selected from the group consisting of gas sensors, photo-detectors, solid-state sensors, infrared spectrometric detectors, ultraviolet detectors, temperature sensors, and flame sensors.

3. The energy recovery system of claim 1 or claim 2, wherein the detector (26) is disposed within the evaporator housing (14).

4. The energy recovery system of any preceding claim, wherein the detector (26) is disposed outside of the evaporator housing (14).

5. The energy recovery system of any preceding claim, wherein the inert gas source (34) comprises an inert gas selected from the group consisting of nitrogen, argon, carbon dioxide, and combinations of two or more of the foregoing gases.

6. A method of energy recovery from an organic Rankine cycle system comprising:

(i) introducing a heat source gas (58) into an evaporator apparatus (12) comprising a heat exchange tube (20) containing a working fluid (40);

(ii) transferring heat from the heat source gas (58) to the working fluid (40) to provide a heated working fluid;

(iii) transferring energy from the heated working fluid to a work extraction device (42) located outside of the evaporator apparatus (12);

(iv) returning the working fluid (40) to the evaporator apparatus (12);

wherein the method is carried out in an organic Rankine cycle energy recovery system config-

- ured to detect the working fluid (40) or a combustion by-product thereof and to generate a signal in response to the detection, and wherein the organic Rankine cycle energy recovery system is configured to receive the signal from the detector at a controller, and wherein the controller is configured to actuate an inert gas source upstream of the evaporator in response the signal, and wherein the controller is configured to divert the heat source gas into a heat source gas by-pass in response the signal, and wherein the controller (36) is configured to prevent introduction of a working fluid (40) into the evaporator apparatus (12) in response the signal.
7. The method according to claim 6, wherein the organic Rankine cycle energy recovery system comprises:
- (a) an evaporator apparatus (12) comprising a housing (14), a heat source gas inlet (16), a heat source gas outlet (18), a working fluid inlet (22), a working fluid outlet (24), and a heat exchange tube (20) disposed within the housing (14) and in fluid communication with the working fluid inlet (22) and the working fluid outlet (24);
 - (b) a detector (26) capable of sensing the working fluid or a combustion by-product thereof;
 - (c) a work extraction device (42);
 - (d) a condenser (30);
 - (e) a pump (32);
 - (f) an inert gas source (34) disposed upstream of the evaporator apparatus (12);
 - (g) a controller (36) configured to receive an output from the detector (26); and
 - (h) a heat source gas by-pass (38), wherein the controller (36) is configured to actuate the inert gas source (34), and wherein the controller (36) is configured to divert a heat source gas to the heat source gas by-pass (38), and wherein the controller (36) is configured to prevent introduction of a working fluid (40) into the evaporator apparatus (12).
8. The method according to claim 6 or claim 7, wherein the working fluid (40) is selected from the group consisting of methylcyclopentane, methylcyclobutane, cyclopentane, isopentane, and cyclohexane.
9. The method according to any of claims 6 to 8, wherein the heat source gas (58) is flue gas.
10. An evaporator apparatus for use in an organic Rankine cycle energy recovery system, comprising:

a housing (14), a heat source gas inlet (16), a heat source gas outlet (18), a working fluid inlet (22), a working fluid outlet (24), a heat exchange tube (20) disposed within the housing (14) and in fluid communication with the working fluid inlet (22) and the working fluid outlet (24), and a detector (26) capable of sensing the working fluid (40), or a combustion by-product thereof, wherein the working fluid inlet (22) is coupled to a valve (46) configured to be switchable between a working fluid source (72) and an inert gas source (34).

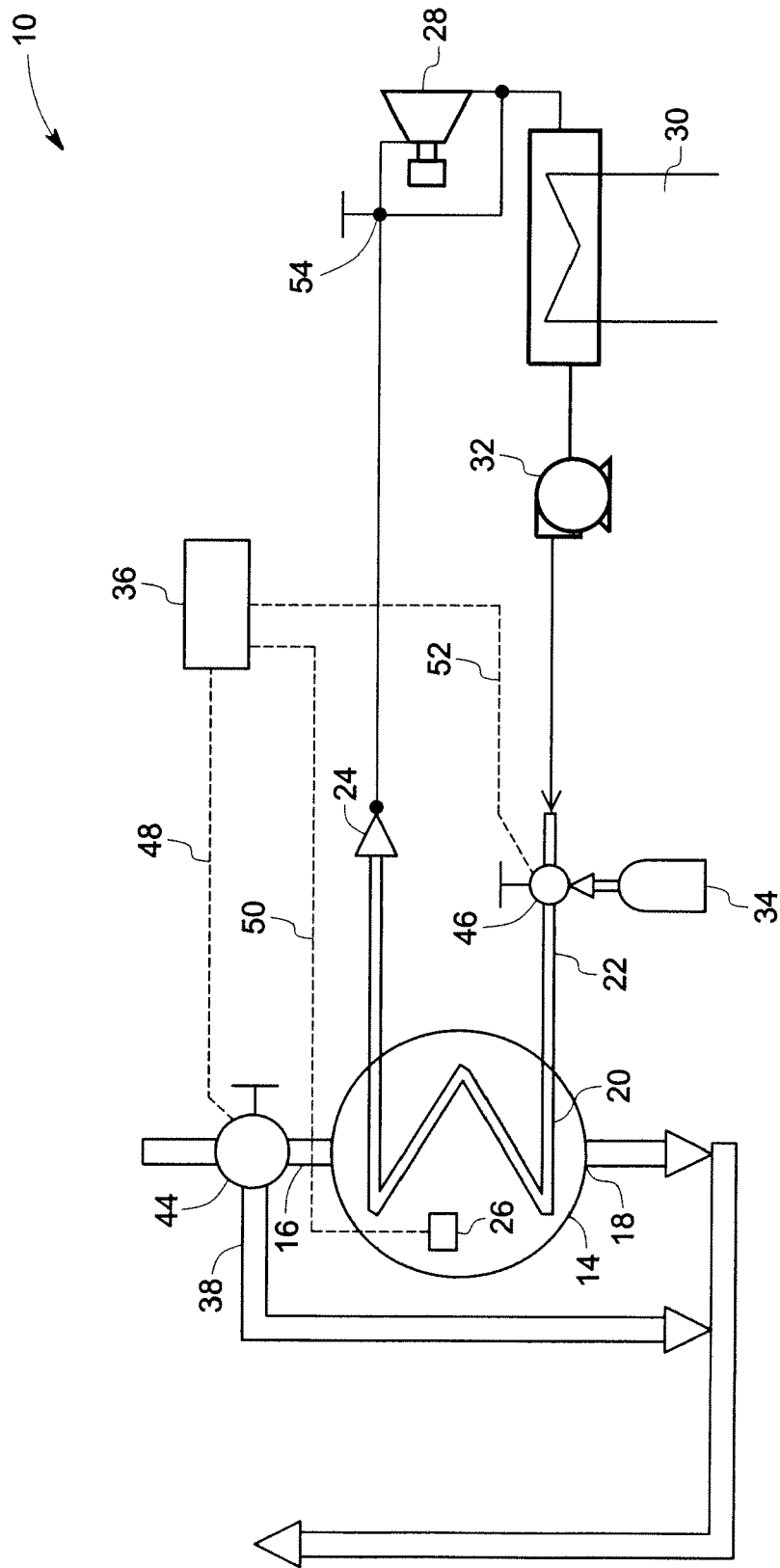


FIG. 1

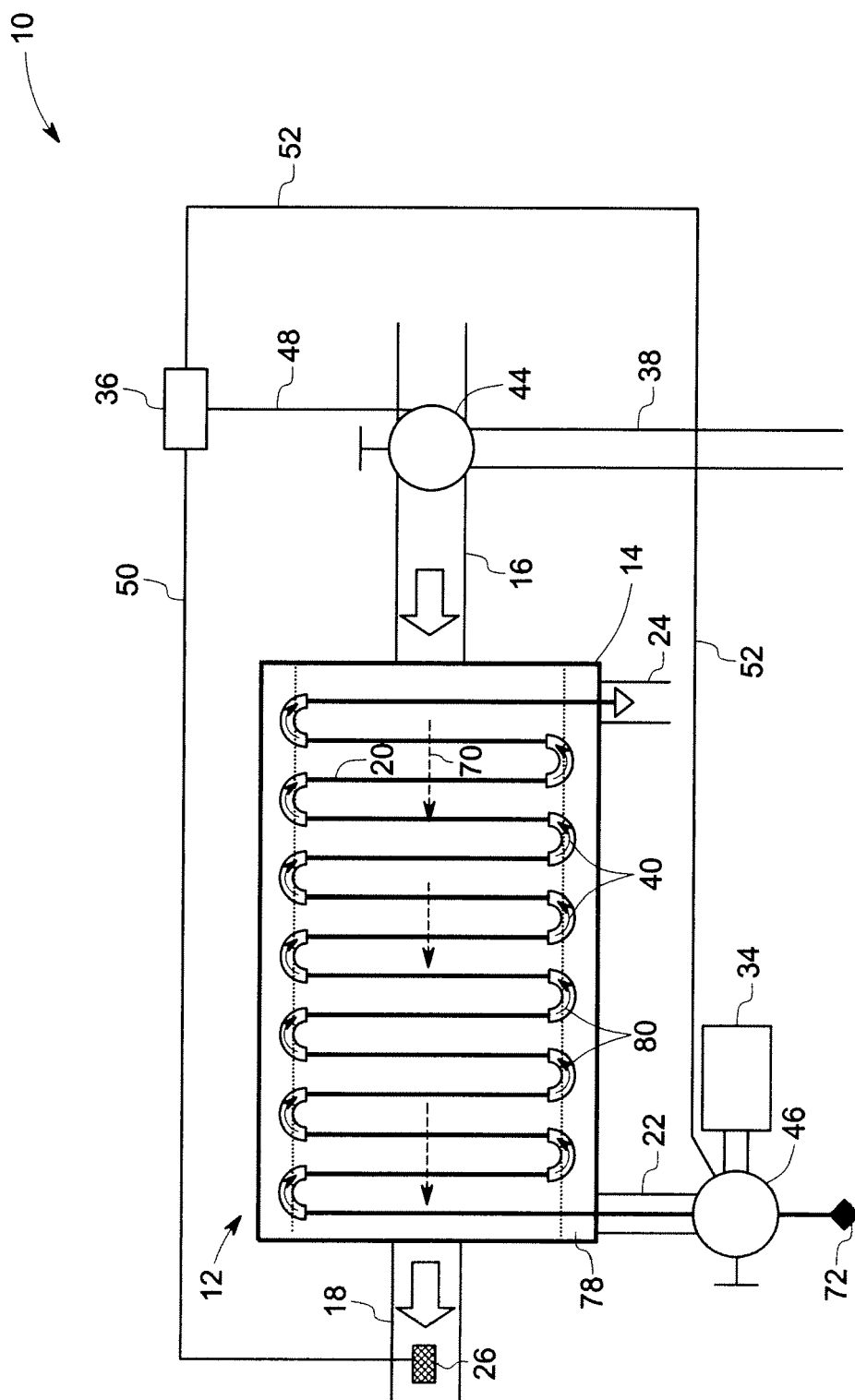


FIG. 2

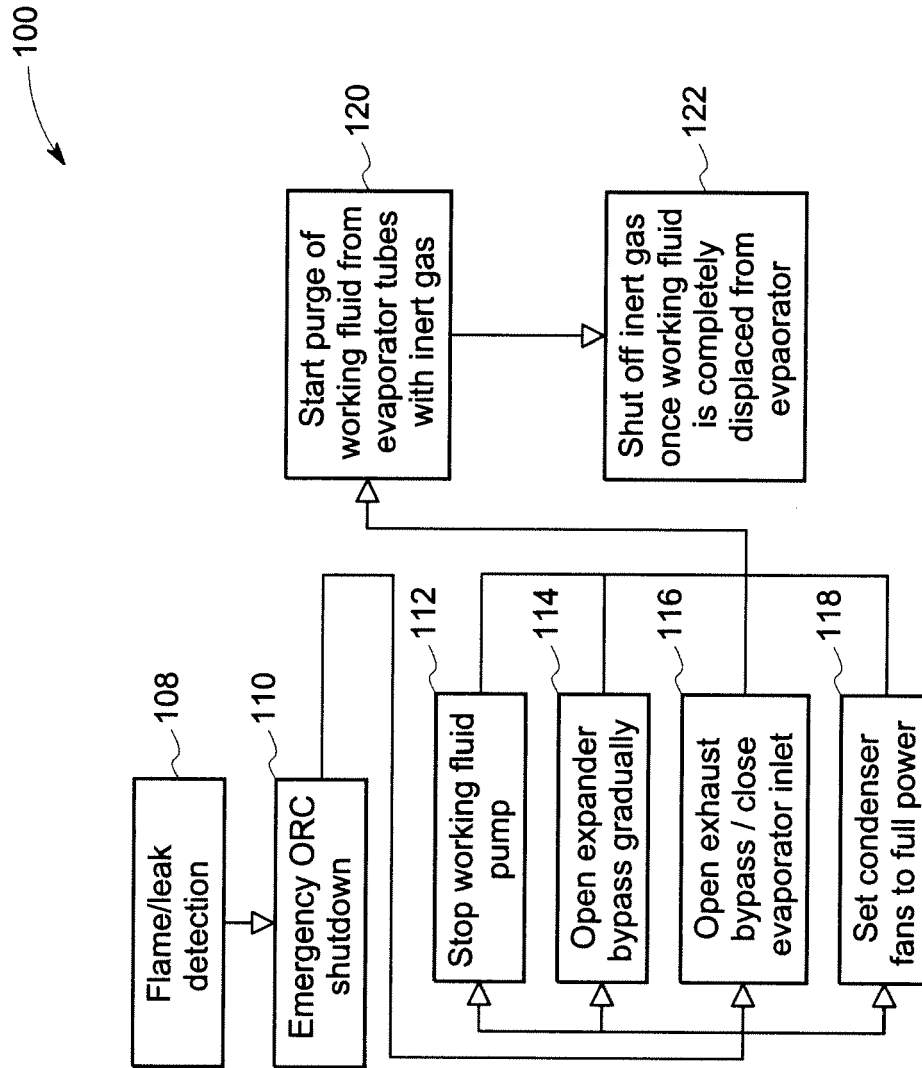


FIG. 3