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(54) **OPTIMIZED SYSTEM FOR RECOVERING WASTE HEAT**

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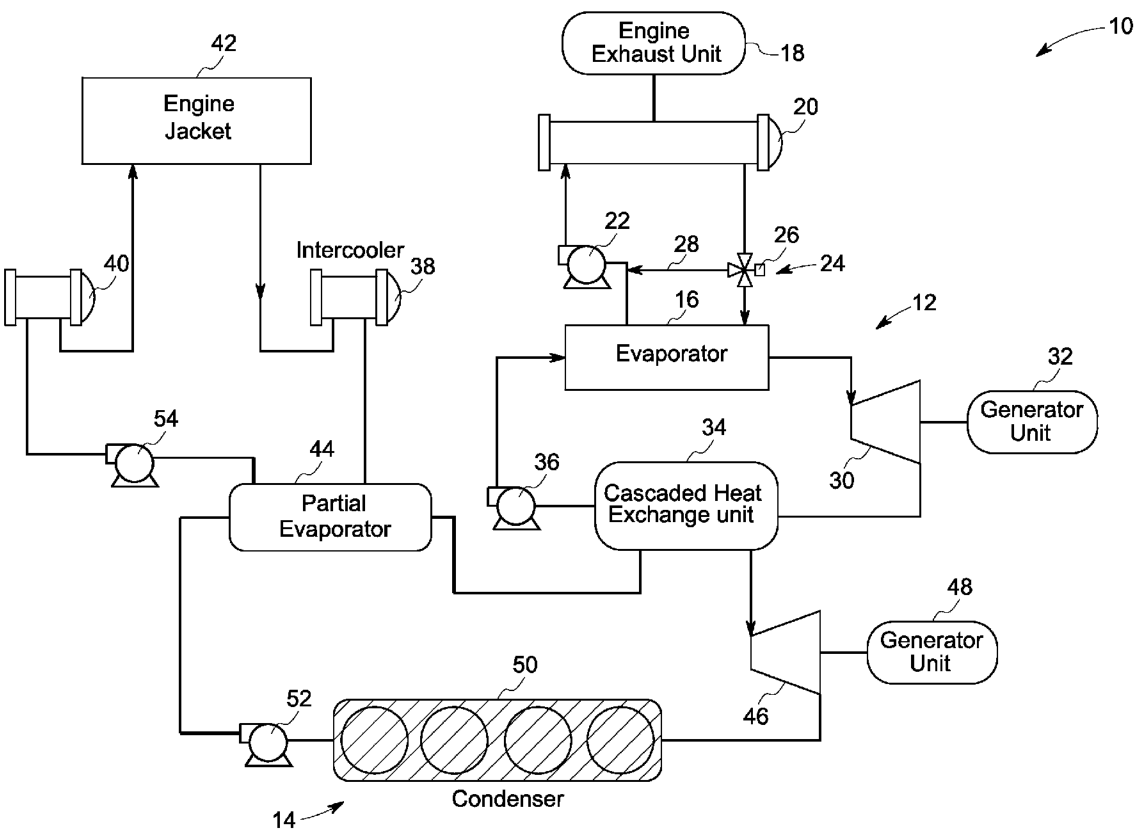
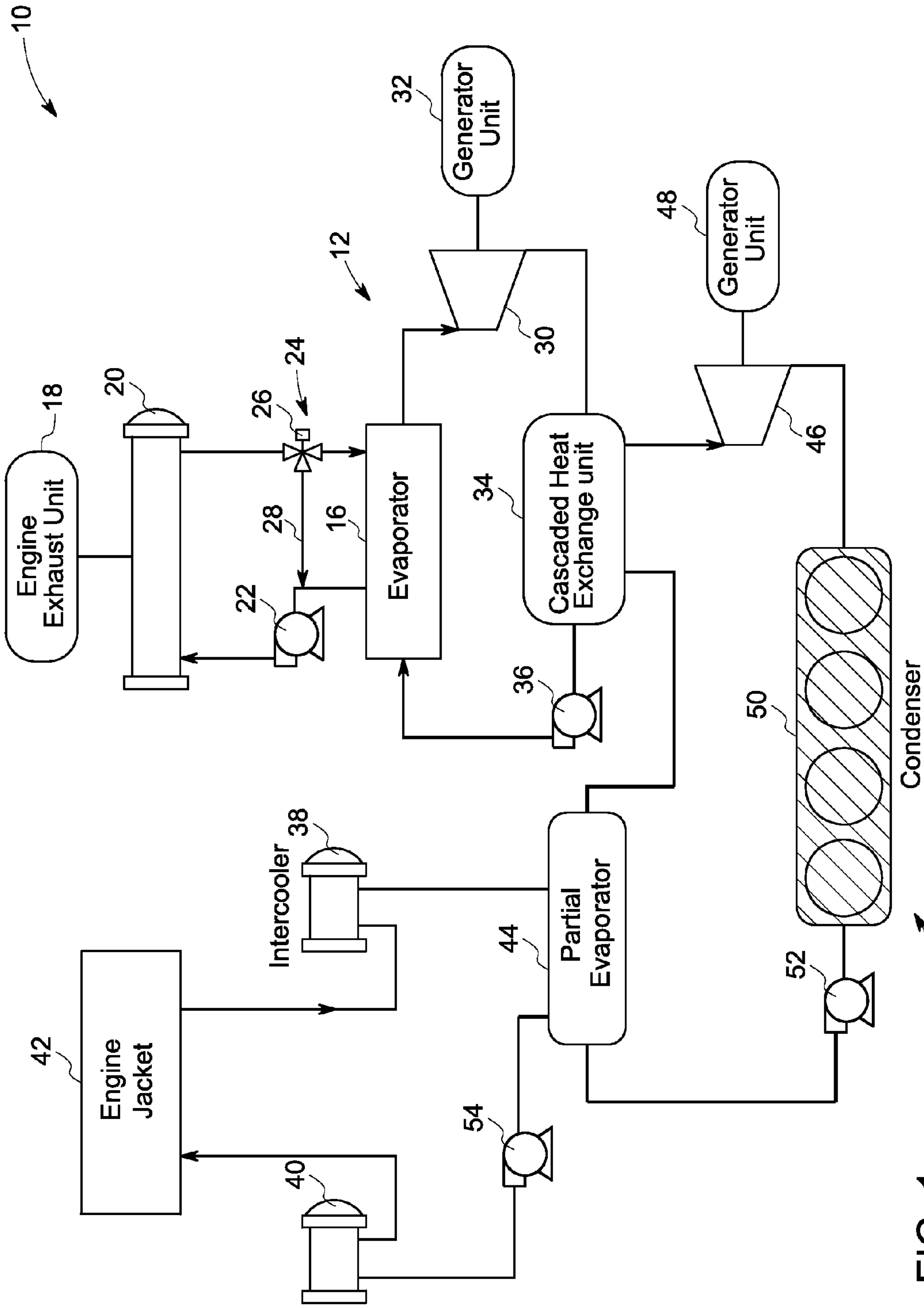
(57) **ABSTRACT**

A waste heat recovery system includes at least two integrated rankine cycle systems coupled to at least two separate heat sources having different temperatures. The first rankine cycle system is coupled to a first heat source and configured to circulate a first working fluid. The second rankine cycle system is coupled to at least one second heat source and configured to circulate a second working fluid. The first and second working fluid are circulatable in heat exchange relationship through a cascading heat exchange unit for condensation of the first working fluid in the first rankine cycle system and evaporation of the second working fluid in the second rankine cycle system. At least one bypass unit is configured to divert at least a portion of the first working fluid to bypass the first evaporator, the first expander, the cascaded heat exchange unit, or combinations thereof; at least a portion of the second working fluid to bypass the second expander, the cascaded heat exchange unit, or combinations thereof.

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12
14
Engine Exhaust Unit
18
20
22
24
26
28
16
Evaporator
30
Generator Unit
32
Cascaded Heat Exchange unit
34
36
Generator Unit
48
46
Intercooler
38
Engine Jacket
42
40
Partial Evaporator
44
54
Condenser
50
52

FIG. 1

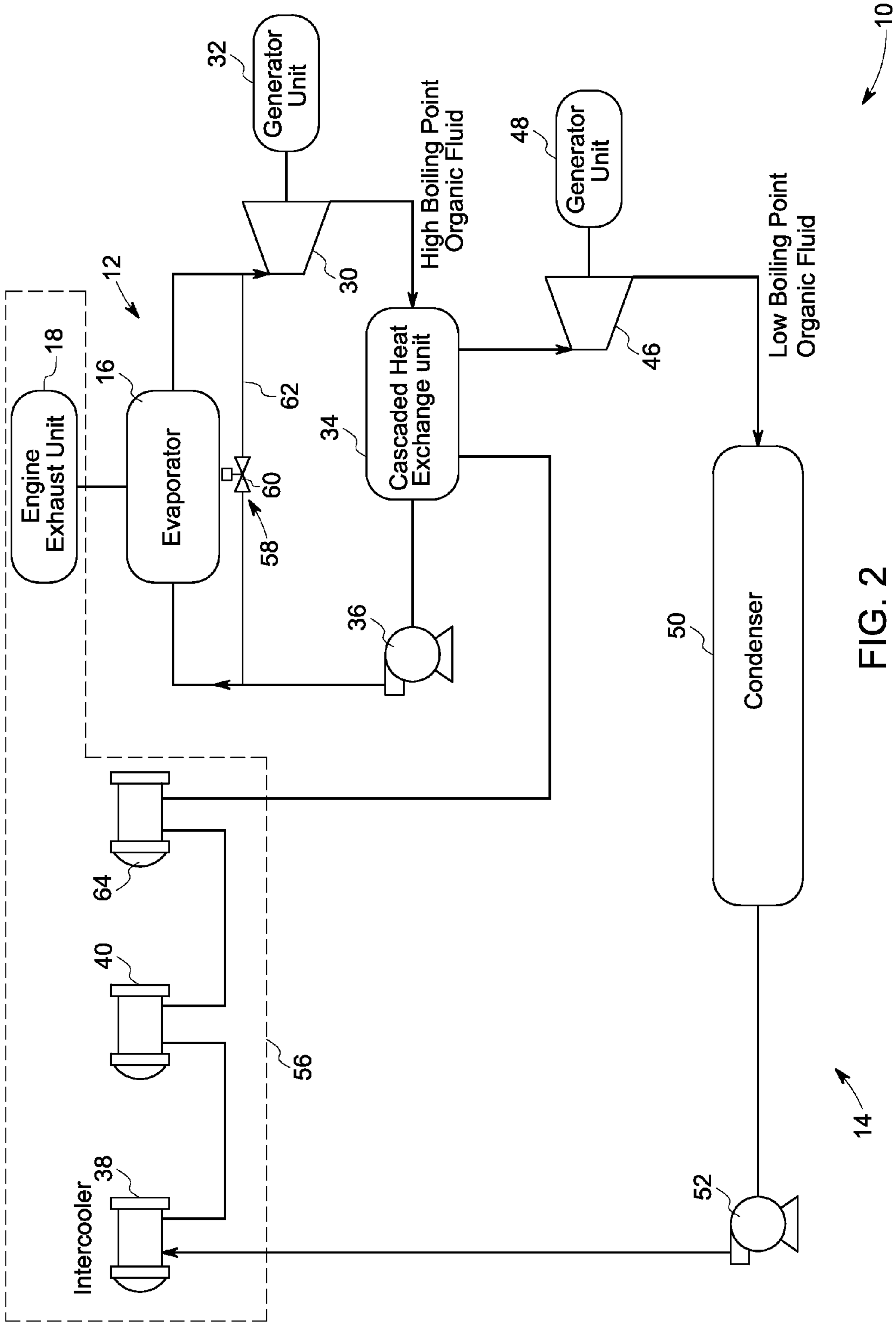

Generator Unit
32
High Boiling Point Organic Fluid
Generator Unit
48
Low Boiling Point Organic Fluid
10
12
30
46
Engine Exhaust Unit
18
Evaporator
16
62
Cascaded Heat Exchange unit
34
60
58
36
Condenser
50
Intercooler
38
40
64
56
14
52

FIG. 2

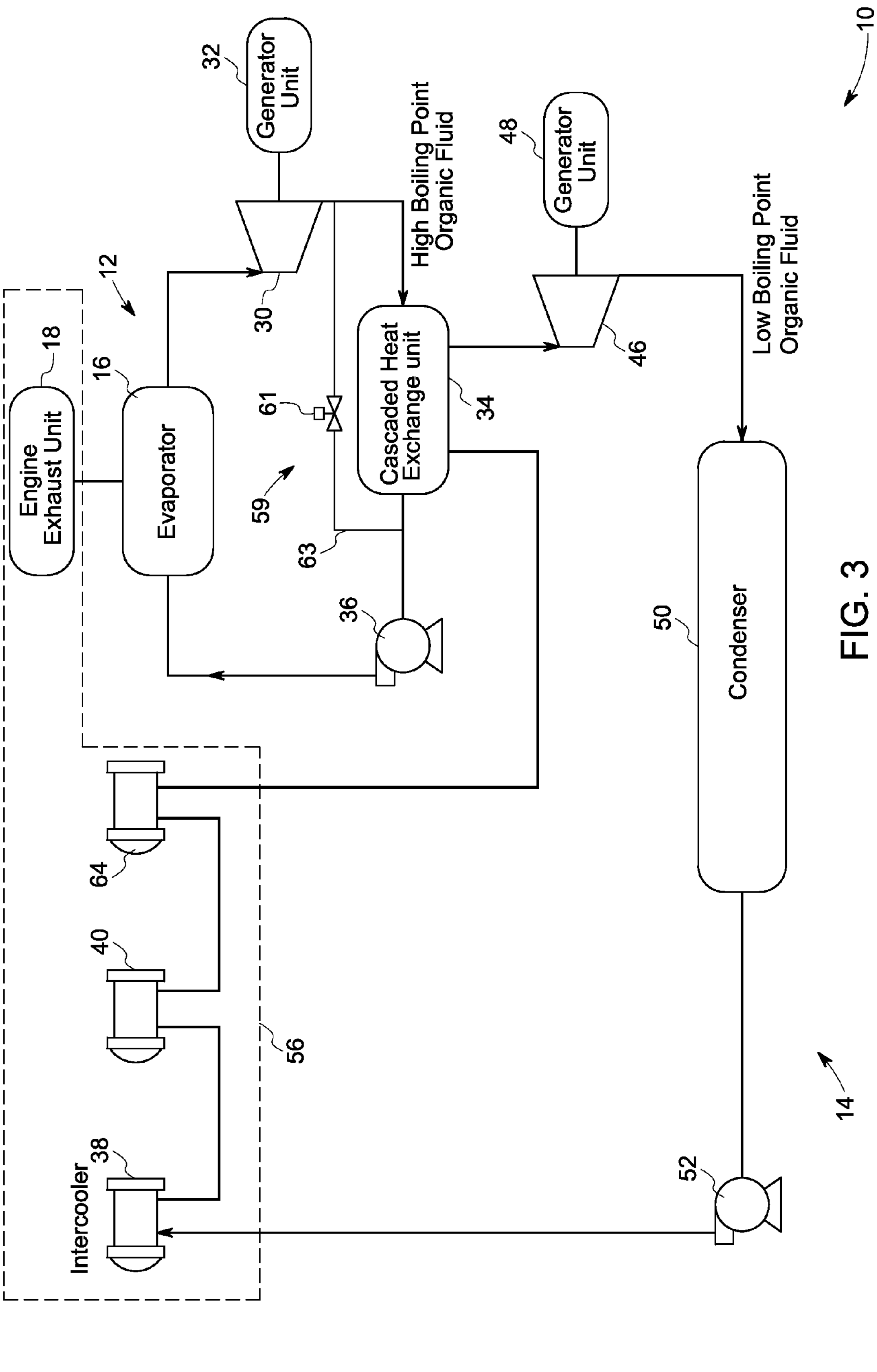
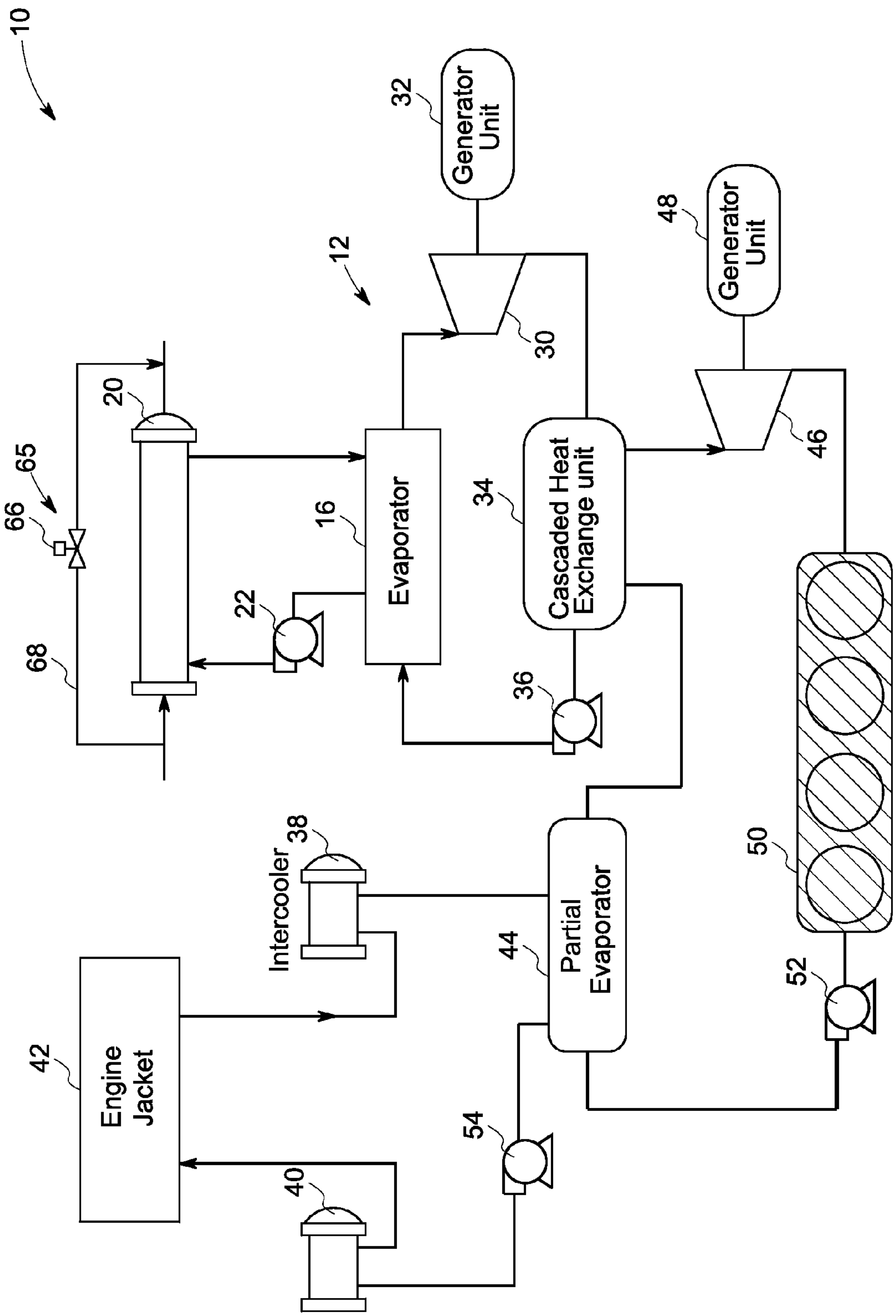

10
12
14
Engine Exhaust Unit
18
Evaporator
16
30
Generator Unit
32
High Boiling Point Organic Fluid
61
59
63
Cascaded Heat Exchange unit
34
36
Generator Unit
48
46
Low Boiling Point Organic Fluid
Condenser
50
52
64
40
56
Intercooler
38

FIG. 3



10
12
14
Generator Unit
32
30
Generator Unit
48
46
20
65
66
68
16
Evaporator
22
Cascaded Heat Exchange unit
34
36
Intercooler
38
Engine Jacket
42
40
Partial Evaporator
44
54
52
Condenser
50

FIG. 4

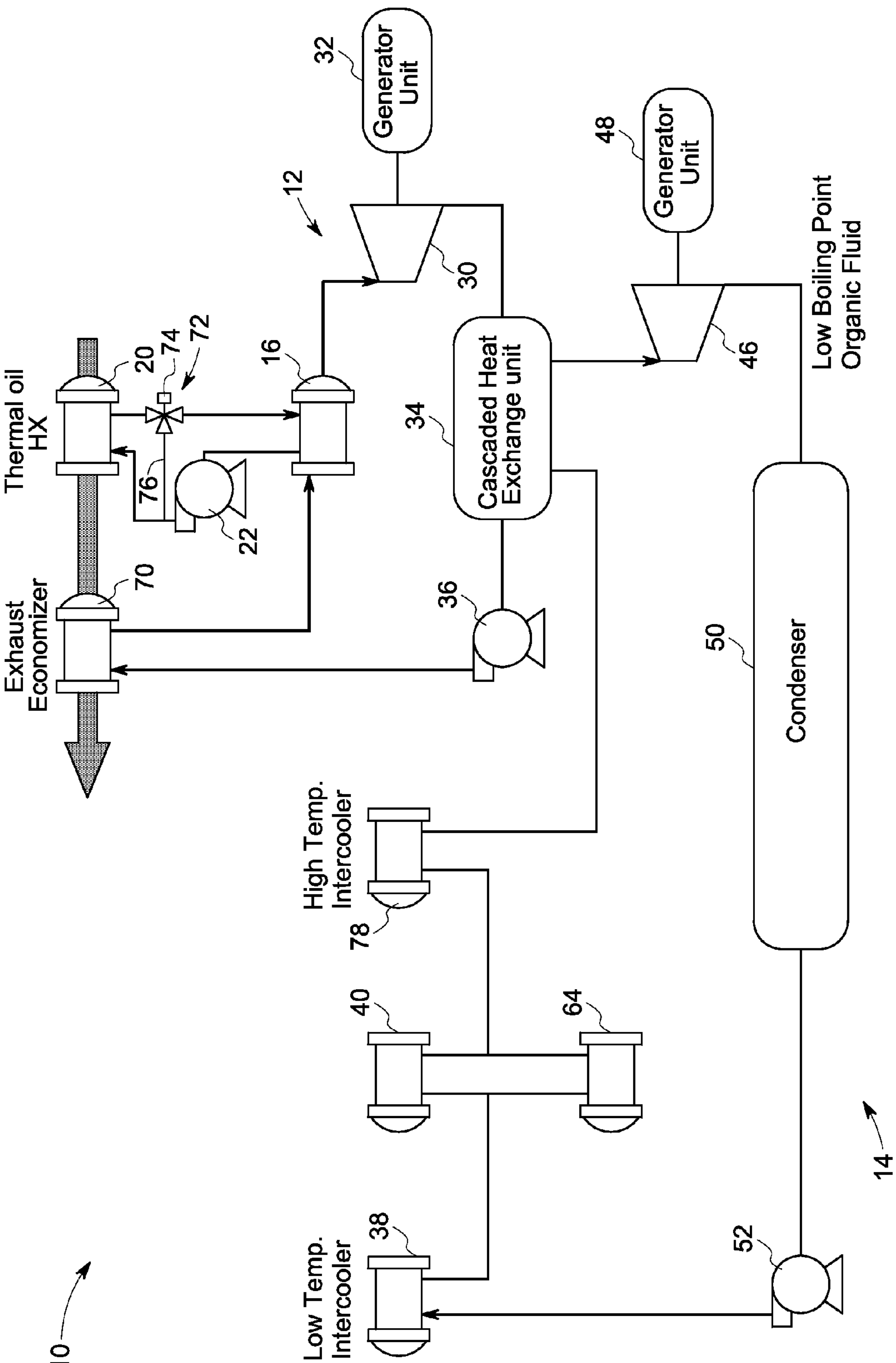
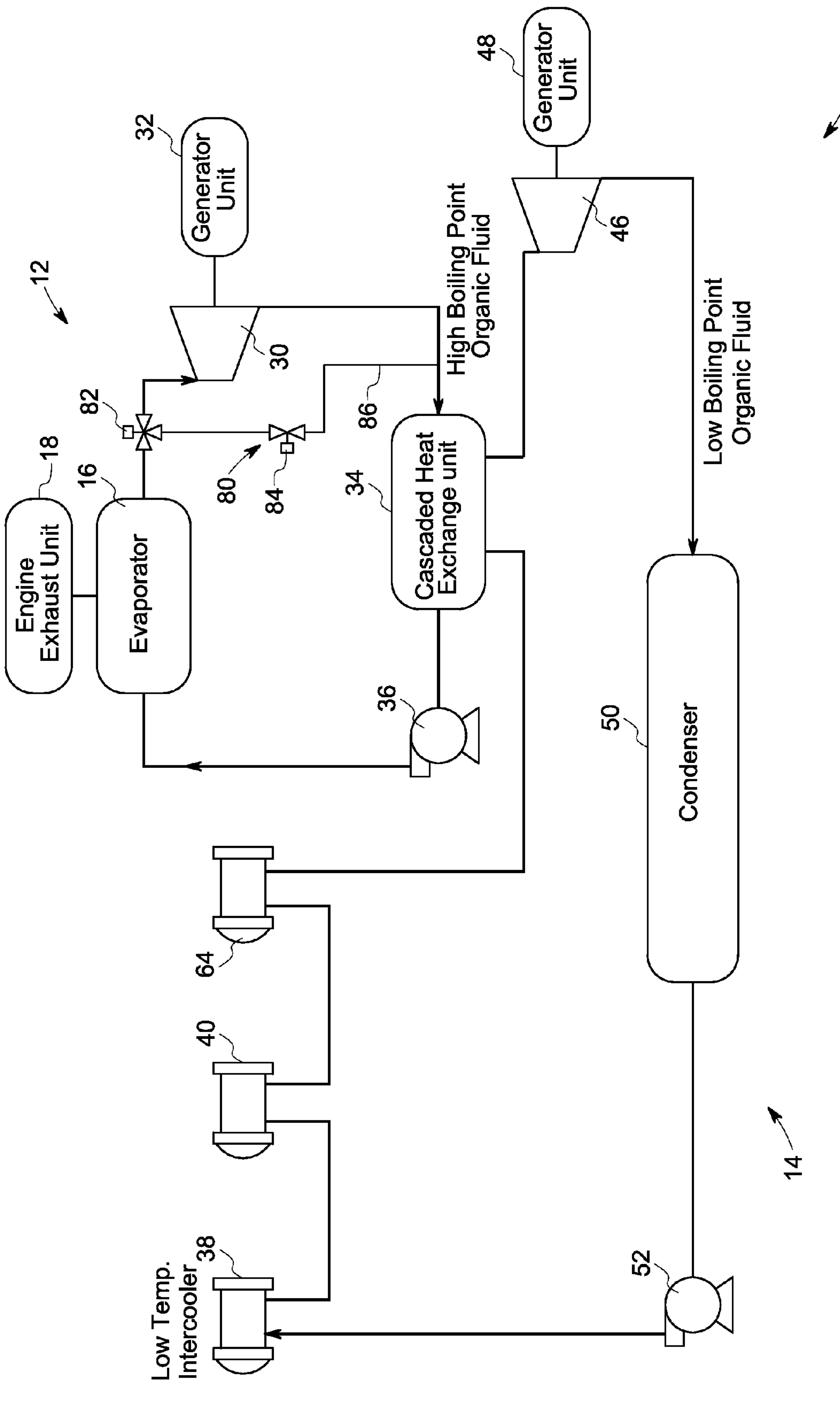

Generator Unit
32
12
30
Generator Unit
48
Low Boiling Point Organic Fluid
46
Thermal oil HX
20
74
72
16
34
Cascaded Heat Exchange unit
76
22
Exhaust Economizer
70
36
50
Condenser
High Temp. Intercooler
78
40
64
14
Low Temp. Intercooler
38
52
10

FIG. 5



10
12
14
Generator Unit
32
Generator Unit
48
30
46
High Boiling Point Organic Fluid
82
86
80
84
18
Engine Exhaust Unit
16
Evaporator
34
Cascaded Heat Exchange unit
Low Boiling Point Organic Fluid
36
50
Condenser
64
40
38
Low Temp. Intercooler
52

FIG. 6

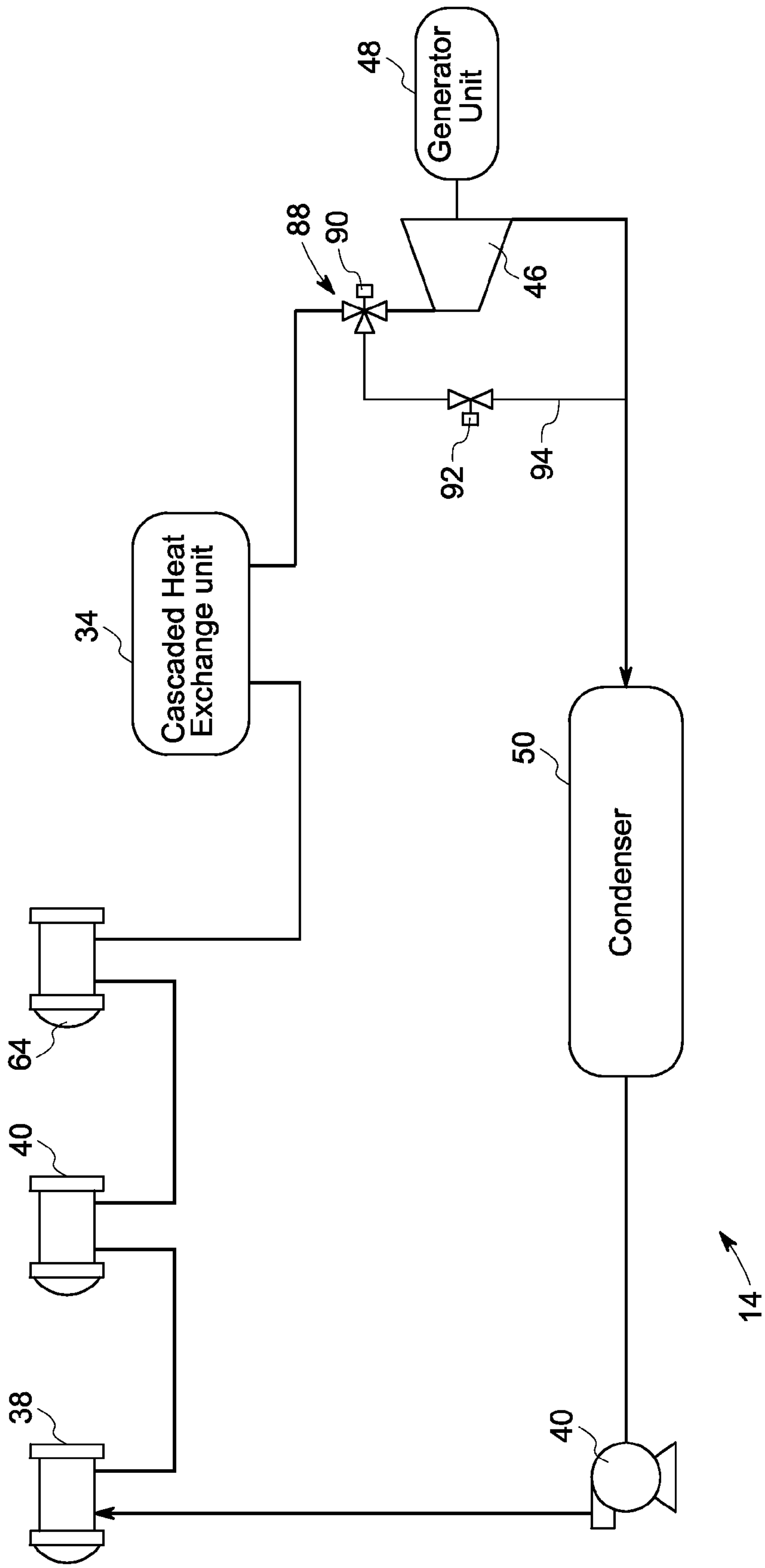

48
Generator Unit
88
90
46
92
94
34
Cascaded Heat Exchange unit
50
Condenser
64
40
38
40
14

FIG. 7

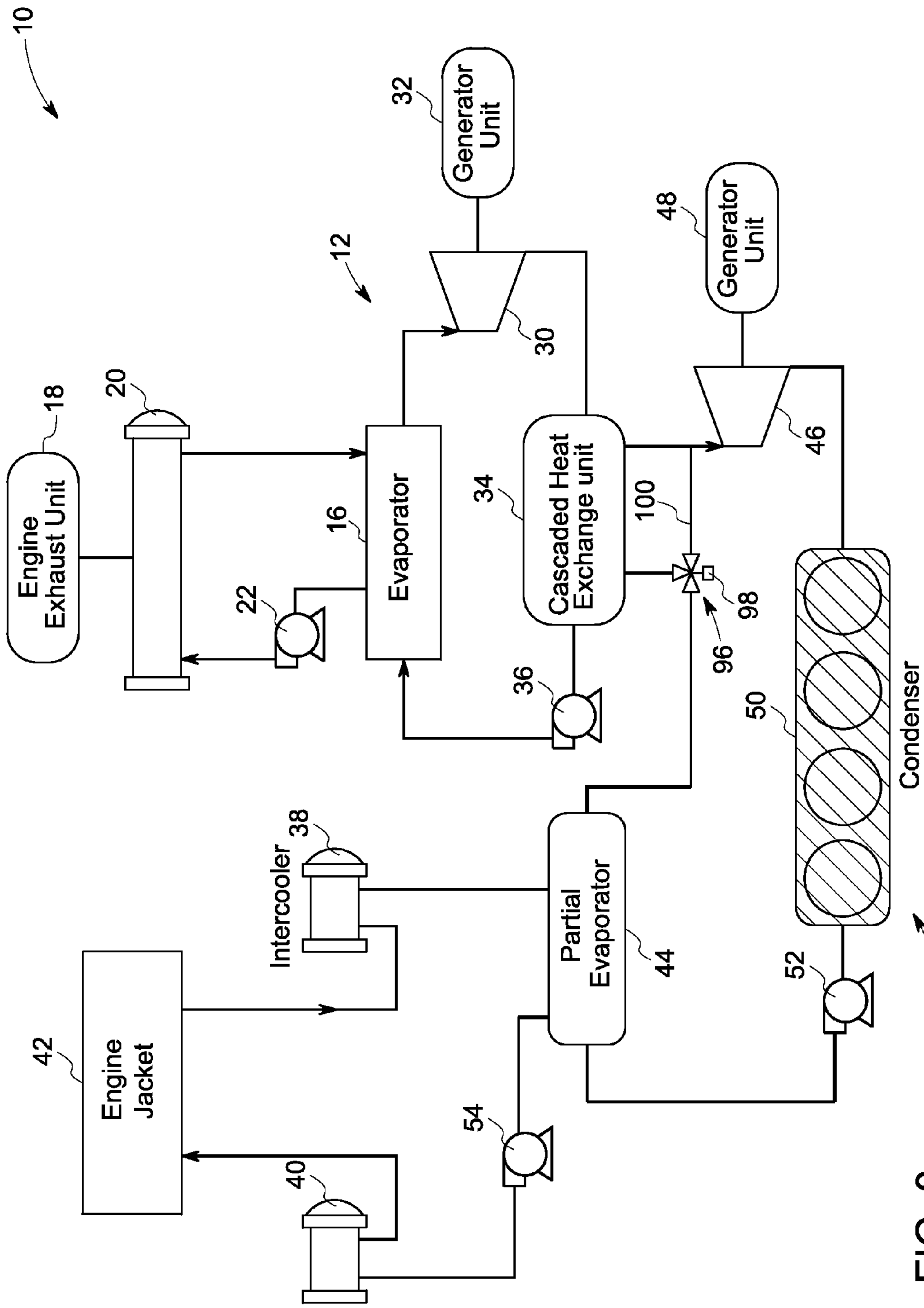
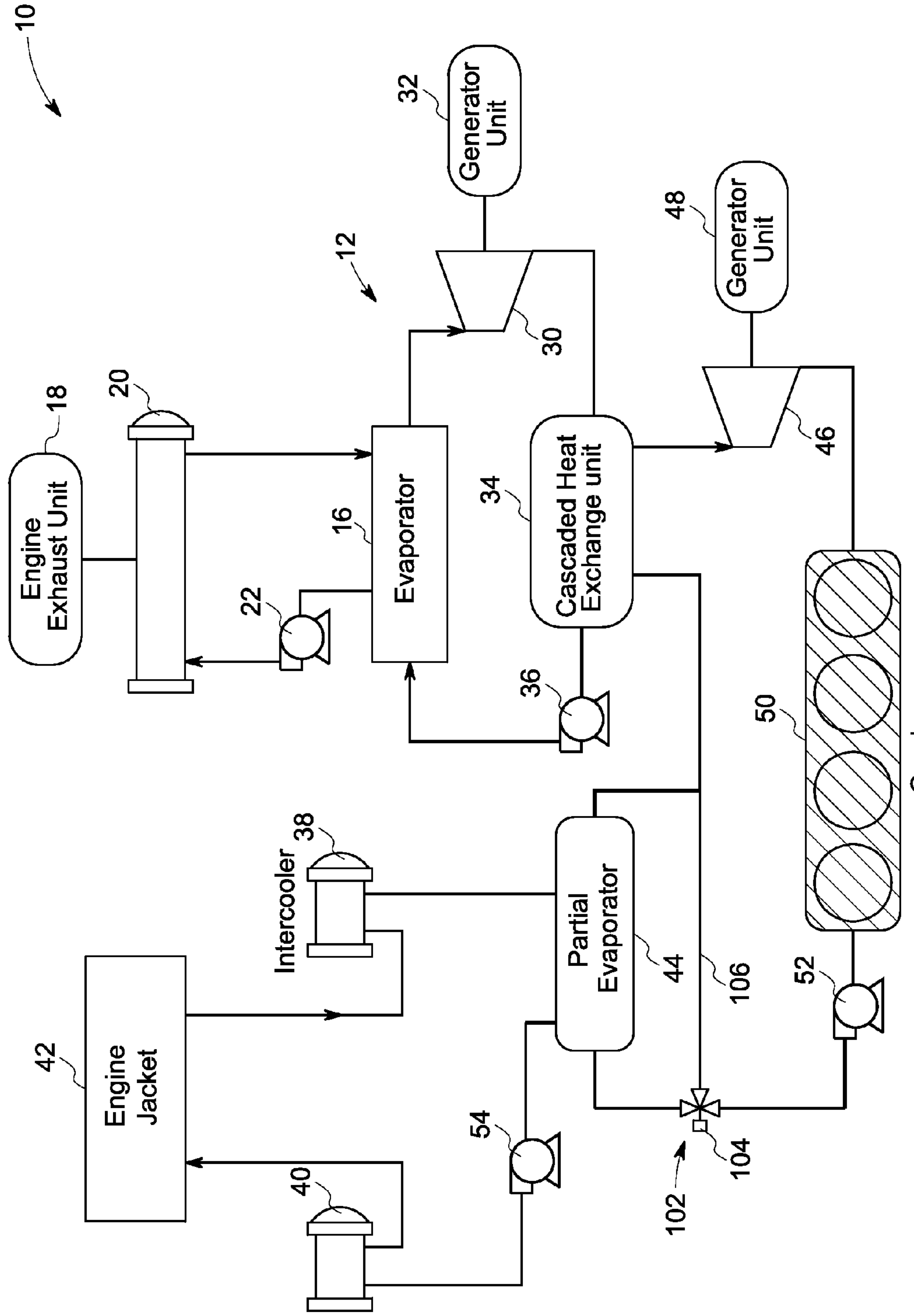

10
12
14
Engine Exhaust Unit
18
20
22
Evaporator
16
Generator Unit
32
30
Cascaded Heat Exchange unit
34
36
Generator Unit
48
46
100
98
96
Condenser
50
52
Intercooler
38
Engine Jacket
42
Partial Evaporator
44
40
54

FIG. 8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12
Engine Exhaust Unit
18
20
22
Evaporator
16
Generator Unit
32
30
Cascaded Heat Exchange unit
34
36
Generator Unit
48
46
Condenser
50
14
52
Intercooler
38
Partial Evaporator
44
106
Engine Jacket
42
40
54
102
104

FIG. 9

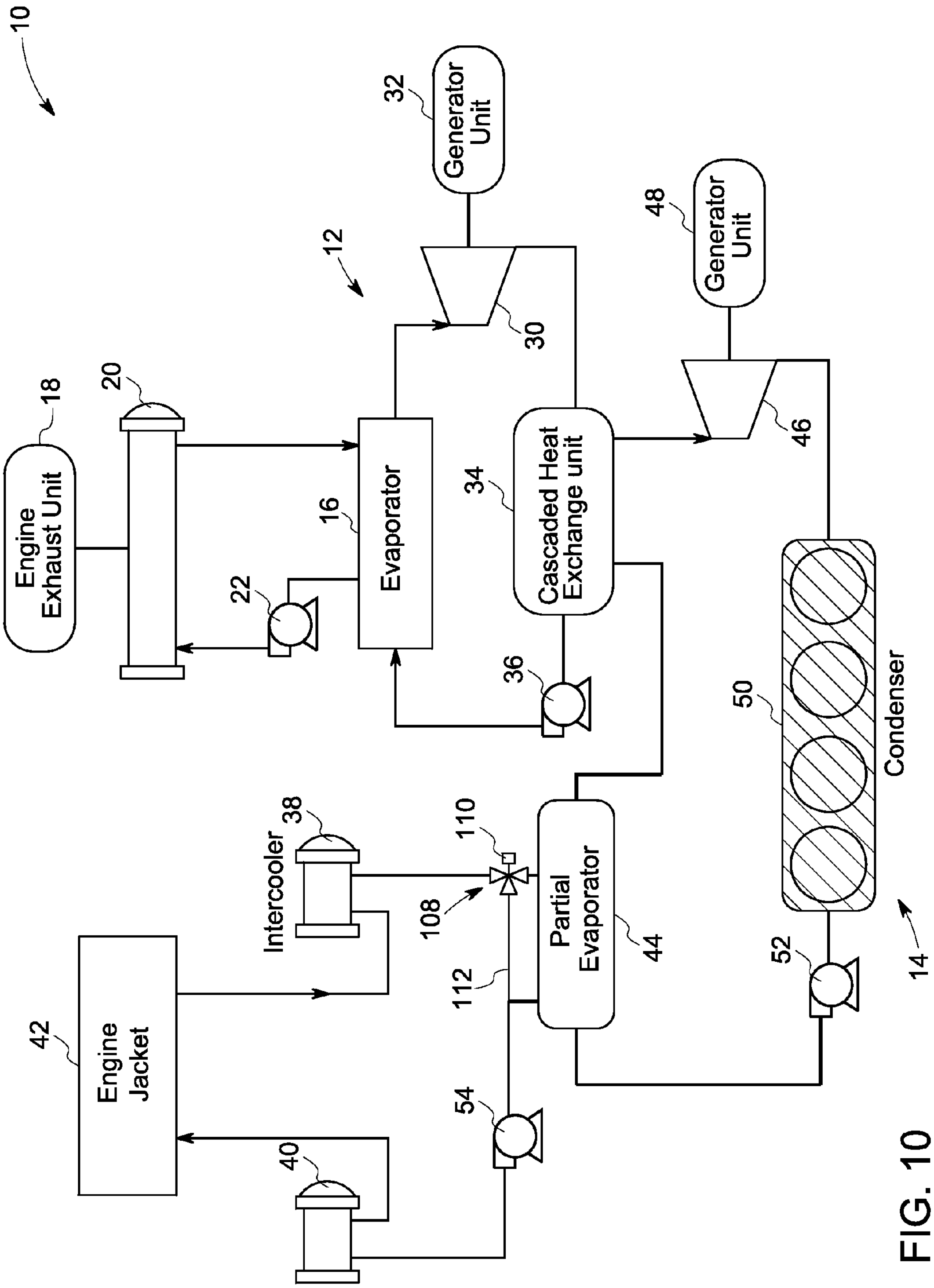
10
12
Generator Unit
32
Generator Unit
48
30
18
Engine Exhaust Unit
20
Evaporator
16
22
Cascaded Heat Exchange unit
34
46
36
Condenser
50
52
14
Intercooler
38
110
108
112
Partial Evaporator
44
Engine Jacket
42
54
40

FIG. 10

OPTIMIZED SYSTEM FOR RECOVERING WASTE HEAT

BACKGROUND

[0001] The embodiments disclosed herein relate generally to the field of power generation and, more particularly, to an optimized system for recovering waste heat from a plurality of heat sources having different temperatures for generation of electricity.

[0002] Enormous amounts of waste heat are generated by a wide variety of industrial and commercial processes and operations. Example sources of waste heat include heat from space heating assemblies, steam boilers, engines, and cooling systems. When waste heat is low grade, such as waste heat having a temperature of heat below 400 degrees Fahrenheit, for example, conventional heat recovery systems do not operate with sufficient efficiency to make recovery of energy cost-effective. The net result is that vast quantities of waste heat are simply dumped into the surroundings.

[0003] Combustion engines are also used to generate electricity using fuels such as gasoline, natural gas, biogas, plant oil, and diesel fuel. However, atmospheric emissions such as nitrogen oxides and particulates may be emitted.

[0004] In one conventional method to generate electricity from waste heat, a two-cycle system is used in heat recovery applications with waste heat sources of different temperature levels. In such two-cycle configurations, the hot heat source heats a high-boiling point liquid in a top loop, and the cold heat source heats a low-boiling point liquid in a separate bottom loop. Since the two-cycle systems are more complex and require more components, the overall cost of the two-cycle system is significantly higher.

[0005] In another conventional system provided to generate electricity from waste heat, a cascaded organic rankine cycle system for utilization of waste heat includes a pair of organic rankine cycle systems. The cycles are combined, and the respective organic working fluids are chosen such that the organic working fluid of the first organic rankine cycle is condensed at a condensation temperature that is above the boiling point of the organic working fluid of the second organic cycle. A single common heat exchanger is used for both the condenser of the first organic rankine cycle system and the evaporator of the second organic rankine cycle. However, performance of such a system may be reduced under different operating conditions. In other words, performance of such a system may be reduced during partial load and varying ambient conditions.

[0006] It is desirable to have an optimized system that effectively recovers waste heat over a wide temperature range from multiple low-grade heat sources at different operating conditions.

BRIEF DESCRIPTION

[0007] In accordance with one exemplary embodiment disclosed herein, a waste heat recovery system including at least two integrated rankine cycle systems is provided. The system includes a heat generation system comprising at least two separate heat sources having different temperatures. A first rankine cycle system is coupled to a first heat source among the at least two separate heat sources and configured to circulate a first working fluid. The first rankine system is configured to remove heat from the first heat source. A second rankine cycle system is coupled to at least one second heat source among the at least two separate heat sources and configured to circulate a second working fluid. The at least one second heat source includes a lower temperature heat source than the first heat source. The second rankine cycle system is configured to remove heat from the at least one second heat source. The first and second working fluids are circulatable in a heat exchange relationship through a cascaded heat exchange unit for condensation of the first working fluid in the first rankine cycle system and evaporation of the second working fluid in the second rankine cycle system. At least one bypass unit is configured to divert at least a portion of the first working fluid to bypass the first evaporator, the first expander, the cascaded heat exchange unit, or combinations thereof; at least a portion of the second working fluid to bypass the second expander, the cascaded heat exchange unit, or combinations thereof.

[0008] In accordance with one exemplary embodiment disclosed herein, a waste heat recovery system including at least two integrated organic rankine cycle systems is provided. The system includes a combustion engine having an engine exhaust unit; and at least another heat source selected from a group comprising an oil heat exchanger, engine jacket, water jacket heat exchanger, lower temperature intercooler, higher temperature intercooler, or combinations thereof. A first organic rankine cycle system is coupled to the engine exhaust unit and configured to circulate a first organic working fluid. A second organic rankine cycle system is coupled to at least one other heat source selected from the group comprising the oil heat exchanger, engine jacket, water jacket heat exchanger, lower temperature intercooler, higher temperature intercooler, or combinations thereof, and configured to circulate a second organic working fluid. The one heat source includes a lower temperature heat source than at least one other heat source. The second organic rankine cycle system is configured to remove heat from the at least one other heat source. The first and second organic working fluids are circulatable in heat exchange relationship through a cascaded heat exchange unit for condensation of the first organic working fluid in the first organic rankine cycle system and evaporation of the second organic working fluid in the second organic rankine cycle system. At least one bypass unit is configured to divert at least a portion of the first working fluid to bypass the first evaporator, the first expander, the cascaded heat exchange unit, or combinations thereof; at least a portion of the second working fluid to bypass the second expander, the cascaded heat exchange unit, or combinations thereof.

DRAWINGS

[0009] 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:

[0010] FIG. **1** is a diagrammatical representation of waste heat recovery system having two integrated organic rankine cycle systems with a bypass arrangement in a thermal oil loop in accordance with an exemplary embodiment disclosed herein;

[0011] FIG. **2** is a diagrammatical representation of waste heat recovery system having two integrated organic rankine cycle systems with a bypass arrangement in a top loop in accordance with an exemplary embodiment disclosed herein;

[0012] FIG. **3** is a diagrammatical representation of waste heat recovery system having two integrated organic rankine cycle systems with a bypass arrangement in a top loop in accordance with an exemplary embodiment disclosed herein;

[0013] FIG. **4** is a diagrammatical representation of waste heat recovery system having two integrated organic rankine cycle systems with a bypass arrangement for flow of exhaust gas in accordance with an exemplary embodiment disclosed herein;

[0014] FIG. **5** is a diagrammatical representation of waste heat recovery system having two integrated organic rankine cycle systems with a bypass arrangement in a thermal oil loop in accordance with an exemplary embodiment disclosed herein;

[0015] FIG. **6** is a diagrammatical representation of waste heat recovery system having two integrated organic rankine cycle systems with a bypass arrangement in a top loop in accordance with an exemplary embodiment disclosed herein;

[0016] FIG. **7** is a diagrammatical representation of waste heat recovery system having two integrated organic rankine cycle systems with a bypass arrangement in a bottom loop in accordance with an exemplary embodiment disclosed herein;

[0017] FIG. **8** is a diagrammatical representation of waste heat recovery system having two integrated organic rankine cycle systems with a bypass arrangement in a bottom loop in accordance with an exemplary embodiment disclosed herein;

[0018] FIG. **9** is a diagrammatical representation of waste heat recovery system having two integrated organic rankine cycle systems with a bypass arrangement in a bottom loop in accordance with an exemplary embodiment disclosed herein; and

[0019] FIG. **10** is a diagrammatical representation of waste heat recovery system having two integrated organic rankine cycle systems with a bypass arrangement in a water loop in accordance with an exemplary embodiment disclosed herein.

DETAILED DESCRIPTION

[0020] As discussed in detail below, embodiments of the present invention provide a waste heat recovery system having at least two integrated rankine cycle systems coupled to at least two separate heat sources respectively having different temperatures. The first rankine cycle system is coupled to a first heat source and configured to circulate a first working fluid. The second rankine cycle system is coupled to at least one second heat source and configured to circulate a second working fluid. The second heat source includes a lower temperature heat source than the first heat source. The waste heat recovery system also includes a cascaded heat exchange unit. The first and second working fluids are circulated in heat exchange relationship for condensation of the first working fluid in the first rankine cycle system and evaporation of the second working fluid in the second rankine cycle system. At least one bypass unit is configured to divert at least a portion of the first working fluid to bypass the first evaporator, the first expander, or combinations thereof; at least a portion of the second working fluid to bypass the second expander, the cascaded heat exchange unit, or combinations thereof. Various bypasses in the exemplary waste heat recovery system allow the optimized operation of the organic rankine cycle system under different operating conditions. These additional degrees of freedom enable high performance at part load and varying ambient conditions without exceeding component limits, such as maximum pressures, temperatures, or the like. Although the waste heat recovery system in the exemplary embodiments of FIGS. **1-10** is described with reference to combustion engines, the system is also applicable to other heat generation systems such as gas turbines, geothermal, solar, industrial and residential heat sources, or the like.

[0021] Referring to FIG. **1**, a waste heat recovery system **10** is illustrated in accordance with an exemplary embodiment of the present invention. The illustrated waste heat recovery system **10** includes a first organic rankine cycle system **12** (top cycle) and a second organic rankine cycle system **14** (bottom cycle). A first organic working fluid is circulated through the first organic rankine cycle system **12**. The first organic working fluid may include cyclohexane, cyclopentane, thiophene, ketones, aromatics, or combinations thereof. In the illustrated embodiment, the first organic rankine cycle system **12** includes the evaporator **16** coupled to a first heat source **18**, i.e. the exhaust unit of the engine, via a thermal oil heat exchanger **20**. In the illustrated embodiment, the thermal oil heat exchanger **20** is a shell and tube type heat exchanger. The thermal oil heat exchanger **20** is used to heat thermal oil to a relatively higher temperature using exhaust gas of the engine. The evaporator **16** receives heat from the thermal oil and generates a first organic working fluid vapor. The thermal oil is then pumped back from the evaporator **16** to the thermal oil heat exchanger **20** using a pump **22**. In another embodiment, the evaporator **16** may be coupled to the first heat source **18** via an exhaust economizer.

[0022] As discussed previously, in conventional systems performance may be reduced under different operating conditions. In other words, performance may be reduced during partial load and varying ambient conditions. In the illustrated embodiment, one bypass unit **24** is configured to divert at least a portion of thermal oil to bypass the evaporator **16**. The bypass unit **24** includes a control valve **26** coupled to a bypass path **28**. The control valve **26** is configured to control the flow of thermal oil through the bypass path **28**. In one embodiment, during partial load conditions or transient conditions, the control valve **26** may be opened so as to divert a portion of heated thermal oil from the thermal oil heat exchanger **20** through the bypass path **28**.

[0023] The first organic working fluid vapor from the evaporator **16** is passed through a first expander **30** (which in one example includes a radial type expander) to drive a first generator unit **32**. In certain other exemplary embodiments, the first expander **30** may be axial type expander, impulse type expander, or high temperature screw type expander. After passing through the first expander **30**, the first organic working fluid vapor at a relatively lower pressure and lower temperature is passed through a cascaded heat exchange unit **34**. The first organic working fluid vapor is condensed into a liquid, which is then pumped via a pump **36** to the evaporator **16**. The cycle may then be repeated.

[0024] The cascaded heat exchange unit **34** is used both as a condenser for the first organic rankine cycle system **12** and as evaporator for the second organic rankine cycle system **14**. A second organic working fluid is circulated through the second organic rankine cycle system **14**. The second organic working fluid may include propane, butane, pentafluoro-propane, pentafluoro-butane, pentafluoro-polyether, oil, or combinations thereof. It should be noted herein that list of first and second organic working fluids are not inclusive and other organic working fluids applicable to organic rankine cycles are also envisaged. In certain other exemplary embodiments, the first or second organic working fluid includes a binary fluid. The binary fluid may include cyclohexane-propane, cyclohexane-butane, cyclopentane-butane, or cyclopentane-pentafluoropropane, for example.

[0025] In the illustrated embodiment, the cascaded heat exchange unit **34** is coupled to a plurality of second heat sources such as an intercooler **38**, an oil heat exchanger **40**, and an engine jacket **42** via a partial evaporator **44**. Such second heat sources are also typically coupled to the engine. It should be noted herein that the second heat source includes a lower temperature heat source than the first heat source. The partial evaporator **44** receives heat from a cooling water loop that collects heat from the oil heat exchanger **40**, the engine jacket **42**, and the intercooler **38** and generates a partially evaporated second organic working fluid two-phase stream. The second organic working fluid stream is passed through the cascaded heat exchange unit **34** for complete evaporation or even superheating of the second organic working fluid. The vaporized second organic working fluid is passed through a second expander **46** to drive a second generator unit **48**. After passing through the second expander **46**, the second organic working fluid vapor at lower pressure and lower temperature is passed through a condenser **50**. The second organic working fluid vapor is condensed into a liquid, which is then pumped via a pump **52** to the partial evaporator **44**. The partial evaporator **44** is configured to partially evaporate the liquid being supplied to the cascaded heat exchange unit **34**. The fluid in the cooling water loop is pumped via a pump **54** to the oil heat exchanger **40**, before being supplied to the engine jacket **42**, and the intercooler **38** before it enters the partial evaporator **44**. The cycle may then be repeated.

[0026] It should be noted that in other exemplary embodiments, first and second heat sources may include other multiple low-grade heat sources such as gas turbines with intercoolers. The cascaded heat exchange unit **24** receives heat from the first organic working fluid and generates a second organic working fluid vapor. The second organic working fluid vapor is passed through a second expander **34** (which in one example includes a screw type compressor) to drive a second generator unit **36**. In certain other exemplary embodiments, the second expander **34** may be a radial type expander, an axial type expander, or an impulse type expander. In certain other exemplary embodiments, the first expander **20** and the second expander **34** are coupled to a single generator unit.

[0027] The cascaded organic rankine cycle system facilitates heat recovery over a temperature range that is too large for a single organic rankine cycle system to accommodate efficiently. The illustrated layout of the second heat sources facilitates effective heat removal from the plurality of lower temperature engine heat sources. This increases the effectiveness of the cooling systems and provides effective conversion of waste heat into electricity.

[0028] In another exemplary embodiment of the present invention, the heat generation system may include a gas turbine system. Steam may be circulated through the top cycle and the second organic working fluid may be circulated through the bottom cycle. Steam is condensed and passed in heat exchange relationship with the second organic working fluid through the cascaded heat exchange unit **34**.

[0029] Referring to FIG. **2**, a waste heat recovery system **10** is illustrated in accordance with an exemplary embodiment of the present invention. The illustrated waste heat recovery system **10** includes the first organic rankine cycle system **12** and the second organic rankine cycle system **14**. In the illustrated embodiment, the first organic rankine cycle system **12** includes the evaporator **16** coupled to the first heat source **18**, for example an exhaust unit of a heat generation system **56** (for example, an engine). The evaporator **16** receives heat from the exhaust gas generated from the first heat source **18** and generates a first organic working fluid vapor. The first organic working fluid vapor is passed through the first expander **30** to drive the first generator unit **32**. After passing through the first expander **20**, the first organic working fluid vapor at a relatively lower pressure and lower temperature is passed through the cascaded heat exchange unit **34**. The first organic working fluid vapor is condensed into a liquid, which is then pumped via the pump **36** to the evaporator **16**.

[0030] In the illustrated embodiment, one bypass unit **58** is configured to divert at least a portion of the condensed first organic working fluid from the pump **36** to bypass the evaporator **16**. The bypass unit **58** includes a control valve **60** coupled to a bypass path **62**. The control valve **60** is configured to control the flow of the first organic working fluid through the bypass path **62**. In one embodiment, during partial load conditions or transient conditions, the control valve **60** may be opened so as to divert a portion of the condensed first organic working fluid from the pump **36** through the bypass path **62**.

[0031] In the illustrated embodiment, the cascaded heat exchange unit **34** may be coupled to any one or more of a plurality of second heat sources such as the intercooler **38**, the oil heat exchanger **40**, and a cooling water jacket heat exchanger **64**. Such second heat sources are also typically coupled to the engine. After passing through the second expander **46**, the second organic working fluid vapor at lower pressure and lower temperature is passed through the condenser **50**. The second organic working fluid vapor is condensed into a liquid, which is then pumped via the pump **52** to the second heat sources. In the illustrated embodiment, the second organic working fluid is pumped sequentially via the intercooler **38**, the oil heat exchanger **40**, and the cooling water jacket heat exchanger **64**.

[0032] Referring to FIG. **3**, a waste heat recovery system **10** is illustrated in accordance with an exemplary embodiment of the present invention. This embodiment is similar to the embodiment discussed with reference to FIG. **2**. In the illustrated embodiment, one bypass unit **59** is configured to divert at least a portion of the expanded first organic working fluid from the first expander **30** to bypass the cascaded heat exchange unit **34**. The bypass unit **59** includes a control valve **61** coupled to a bypass path **63**. The control valve **61** is configured to control the flow of the first organic working fluid through the bypass path **63**. In one embodiment, during partial load conditions or transient conditions, the control valve **61** may be opened so as to divert a portion of the expanded first organic working fluid from the first expander **30** through the bypass path **63**.

[0033] Referring to FIG. **4**, a waste heat recovery system **10** is illustrated in accordance with an exemplary embodiment of the present invention. This embodiment is similar to the embodiment illustrated in FIG. **1**. In the illustrated embodiment, the first organic rankine cycle system **12** includes the evaporator **16** coupled to the first heat source (not shown) via the thermal oil heat exchanger **20**. The thermal oil heat exchanger **20** is used to heat thermal oil to a relatively higher temperature using exhaust gas of the engine. In the illustrated embodiment, one bypass unit **65** is configured to divert at least a portion of the exhaust gas from the first heat source to bypass the thermal oil heat exchanger **20**. The bypass unit **65** includes a control valve **66** coupled to a bypass path **68**. The control valve **66** is configured to control the flow of exhaust gas through the bypass path **68**. In one embodiment, during partial load conditions or transient conditions, the control valve **66** may be opened so as to divert a portion of the exhaust gas from the first heat source through the bypass path **68**.

[0034] Referring to FIG. **5**, a waste heat recovery system **10** is illustrated in accordance with an exemplary embodiment of the present invention. In the illustrated embodiment, the first organic rankine cycle system **12** includes the evaporator **16** coupled to the first heat source, i.e. the exhaust unit of the engine, via the thermal oil heat exchanger **20** and an exhaust economizer **70**. The thermal oil is then pumped back from the evaporator **16** to the thermal oil heat exchanger **42** using the pump **22**. In the illustrated embodiment, the condensed liquid (i.e. first organic working fluid) from the cascaded heat exchange unit **34** is pumped via the pump **36** to the exhaust economizer **70**. The condensed liquid is heated prior to being supplied to the evaporator **16**.

[0035] In the illustrated embodiment, one bypass unit **72** is configured to divert at least a portion of the thermal oil from the pump **22** to bypass the thermal oil heat exchanger **20**. The bypass unit **72** includes a control valve **74** coupled to a bypass path **76**. The control valve **74** is configured to control the flow of thermal oil through the bypass path **76**. In one embodiment, during partial load conditions or transient conditions, the control valve **74** may be opened so as to divert a portion of the thermal oil from the pump **22** through the bypass path **76**.

[0036] In the illustrated embodiment, the cascaded heat exchange unit **34** is coupled to a plurality of second heat sources such as the lower temperature intercooler **38**, the oil heat exchanger **40**, the water jacket heat exchanger **64**, and a higher temperature intercooler **78**. The heat sources disclosed herein may be coupled in series or parallel. The relative positions of the heat sources may also be varied depending upon the requirement.

[0037] Referring to FIG. **6**, a waste heat recovery system **10** is illustrated in accordance with an exemplary embodiment of the present invention. The illustrated waste heat recovery system **10** includes the first organic rankine cycle system **12** and the second organic rankine cycle system **14**. In the illustrated embodiment, the first organic rankine cycle system **12** includes the evaporator **16** coupled to the first heat source **18**. The evaporator **16** receives heat from the exhaust gas generated from the first heat source **18** and generates a first organic working fluid vapor. The first organic working fluid vapor is passed through the first expander **30** to drive the first generator unit **32**. After passing through the first expander **20**, the first organic working fluid vapor at a relatively lower pressure and lower temperature is passed through the cascaded heat exchange unit **34**. The first organic working fluid vapor is condensed into a liquid, which is then pumped via the pump **36** to the evaporator **16**.

[0038] In the illustrated embodiment, one bypass unit **80** is configured to divert at least a portion of the first organic working fluid vapor from the evaporator **16** to bypass the first expander **20**. The bypass unit **80** includes a three-way valve **82** and a pressure reduction valve **84** coupled to a bypass path **86**. The three-way valve **82** is configured to control the flow of first organic working fluid through the bypass path **86**. In one embodiment, during partial load conditions or transient conditions, the three-way valve **82** may be opened so as to divert a portion of the first organic working fluid vapor from the evaporator **16** through the bypass path **86**. The pressure reduction valve **84** is configured to control the pressure of the first organic working fluid vapor flowing through the bypass path **86**.

[0039] Referring to FIG. **7**, a waste heat recovery system **10** is illustrated in accordance with another exemplary embodiment of the present invention. In the illustrated embodiment, the cascaded heat exchange unit **34** is coupled to a plurality of second heat sources such as the intercooler **38**, the oil heat exchanger **40**, and the water jacket heat exchanger **64**. The second heat sources are used to preheat or partially vaporize the second organic working fluid entering the cascading heat exchange unit **34**. The cascaded heat exchange unit **34** receives heat from the first organic working fluid and generates a second organic working fluid vapor. The second organic working fluid vapor is fed to the second expander **46** to drive the second generator unit **48**. After passing the second organic working fluid through the second expander **46**, the second organic working fluid vapor at lower pressure and lower temperature is passed through the condenser **50**. The second organic working fluid vapor is condensed into a liquid, which is then pumped via the pump **52** to the lower temperature intercooler **38**.

[0040] In the illustrated embodiment, one bypass unit **88** is configured to divert at least a portion of the second organic working fluid vapor from the cascaded heat exchange unit **34** to bypass the second expander **46**. The bypass unit **88** includes a three-way valve **90** and a pressure reduction valve **92** coupled to a bypass path **94**. The three-way valve **90** is configured to control the flow of second organic working fluid through the bypass path **94**. In one embodiment, during partial load conditions or transient conditions, the three-way valve **90** may be opened so as to divert a portion of the second organic working fluid vapor from the cascaded heat exchange unit **34** through the bypass path **94**. The pressure reduction valve **92** is configured to control the pressure of the second organic working fluid vapor flowing through the bypass path **94**.

[0041] Referring to FIG. **8**, a waste heat recovery system **10** is illustrated in accordance with another exemplary embodiment of the present invention. In the illustrated embodiment, the cascaded heat exchange unit **34** is coupled to a plurality of second heat sources such as the intercooler **38**, the oil heat exchanger **40**, and the engine jacket **42** via the partial evaporator **44**. The partial evaporator **44** receives heat from a cooling water loop that collects heat from the oil heat exchanger **40**, the engine jacket **42**, and the intercooler **38** and generates a partially evaporated second organic working fluid two-phase stream. The second organic working fluid stream is passed through the cascaded heat exchange unit **34** for complete evaporation or even superheating of the second organic working fluid. The vaporized second organic working fluid is passed through the second expander **46** to drive the second generator unit **48**. After passing through the second expander **46**, the second organic working fluid vapor at lower pressure and lower temperature is passed through the condenser **50**. The second organic working fluid vapor is condensed into a liquid, which is then pumped via the pump **52** to the partial evaporator **44**.

[0042] In the illustrated embodiment, one bypass unit **96** is configured to divert at least a portion of the second organic working fluid from the partial evaporator **44** to bypass the cascaded heat exchange unit **34**. The bypass unit **96** includes a control valve **98** coupled to a bypass path **100**. The control valve **98** is configured to control the flow of second organic working fluid through the bypass path **100**. In one embodiment, during partial load conditions or transient conditions, the control valve **98** may be opened so as to divert a portion of the second organic working fluid from the partial evaporator **44** through the bypass path **100**.

[0043] Referring to FIG. **9**, a waste heat recovery system **10** is illustrated in accordance with another exemplary embodiment of the present invention. This embodiment is similar to the embodiment illustrated in FIG. **8**. In the illustrated embodiment, one bypass unit **102** is configured to divert at least a portion of the condensed second organic working fluid from the pump **52** to bypass the partial evaporator **44**. The bypass unit **102** includes a control valve **104** coupled to a bypass path **106**. The control valve **104** is configured to control the flow of the condensed second organic working fluid through the bypass path **106**. In one embodiment, during partial load conditions or transient conditions, the control valve **104** may be opened so as to divert a portion of the condensed second organic working fluid from the pump **52** through the bypass path **106**.

[0044] Referring to FIG. **10**, a waste heat recovery system **10** is illustrated in accordance with another exemplary embodiment of the present invention. This embodiment is also similar to the embodiment illustrated in FIG. **8**. In the illustrated embodiment, one bypass unit **108** is configured to divert at least a portion of water (mixture of water and glycol) from the intercooler **38** to bypass the partial evaporator **44**. The bypass unit **108** includes a control valve **110** coupled to a bypass path **112**. The control valve **110** is configured to control the flow of water through the bypass path **112**. In one embodiment, during partial load conditions or transient conditions, the control valve **110** may be opened so as to divert a portion of water from the intercooler **38** through the bypass path **112**.

[0045] It should be noted herein with the reference to embodiments discussed above, a bypass unit may include a three-way valve (for example, as discussed in embodiments of FIGS. **6** and **7**), a control valve (for example, as discussed in embodiments of FIGS. **1-5**, and FIGS. **8-10**), a pressure reduction valve (for example, as discussed in embodiments of FIGS. **6** and **7**), or combinations thereof coupled to a bypass path. In certain embodiments, a three-way valve may be used as a "splitter" and may be disposed upstream of a component to be bypassed. In some other embodiments, a three-way valve may be used as a "mixer" and may be disposed downstream of a component to be bypassed. In a particular embodiment, a control valve may also be a three-way valve.

[0046] With reference to the embodiments discussed above, although one evaporator **16**, one cascaded heat exchange unit **34**, and one partial evaporator **44** is shown, in some embodiments, more than one evaporator **16**, cascaded heat exchange unit **34**, partial evaporator **44** may be used. In such embodiments, an exemplary bypass unit may be provided across the more than one evaporator **16**, cascaded heat exchange unit **34**, and partial evaporator **44**.

[0047] The various bypass arrangements discussed herein with reference to FIGS. **1-9** enhances thermodynamic efficiency and effective heat recovery of the overall system. It should be noted herein that in other embodiments of the exemplary recuperated waste heat recovery system, the number of second heat sources such as intercoolers, oil heat exchangers, jacket heat exchangers, evaporators and their relative positions and their relative positions in the second organic rankine cycle system may be varied depending the application. All such permutations and combinations are envisaged. Various such permutations and combinations discussed in U.S. patent application No. 11/770,895 filed on Jun. 29, 2007 is incorporated herein by reference.

[0048] While only certain features of the invention have been illustrated and described herein, many modifications and changes will occur to those skilled in the art. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.

1. A waste heat recovery system including at least two integrated rankine cycle systems, the recovery system comprising:

a heat generation system comprising at least two separate heat sources having different temperatures;

a first rankine cycle system comprising a first evaporator and a first expander, wherein the first rankine cycle system is coupled to a first heat source among the at least two separate heat sources and configured to circulate a first working fluid; wherein the first rankine system is configured to remove heat from the first heat source;

a second rankine cycle system comprising a second evaporator and a second expander; wherein the second rankine cycle system is coupled to at least one second heat source among the at least two separate heat sources and configured to circulate a second working fluid, the at least one second heat source comprising a lower temperature heat source than the first heat source, wherein the second rankine cycle system is configured to remove heat from the at least one second heat source;

a cascaded heat exchange unit, wherein the first and second working fluids are circulatable in heat exchange relationship through the cascaded heat exchange unit for condensation of the first working fluid in the first rankine cycle system and evaporation of the second working fluid in the second rankine cycle system; and

at least one bypass unit configured to divert at least a portion of the first working fluid to bypass the first evaporator, the first expander, the cascaded heat exchange unit, or combinations thereof; at least a portion of the second working fluid to bypass the second expander, the cascaded heat exchange unit, or combinations thereof.

2. The recovery system of claim **1**, wherein the first evaporator is coupled to the first heat source, and wherein the first heat source comprises an engine exhaust unit.

3. The recovery system of claim **2**, wherein the first evaporator is coupled to the engine exhaust unit via a thermal oil heat exchanger, exhaust economizer, or combinations thereof.

4. The recovery system of claim **3**, further comprising one bypass unit configured to divert at least a portion of thermal oil to bypass the first evaporator; wherein the one bypass unit comprises a control valve coupled to a bypass path.

5. The recovery system of claim **3**, further comprising one bypass unit configured to divert at least a portion of thermal oil to bypass the thermal oil heat exchanger; wherein the one bypass unit comprises a control valve coupled to a bypass path.

6. The recovery system of claim **2**, further comprising one bypass unit configured to divert at least a portion of engine exhaust gas to bypass the thermal oil heat exchanger; wherein the one bypass unit comprises a control valve coupled to a bypass path.

7. The recovery system of claim **1**, wherein the second rankine cycle system comprises a condenser coupled to the at least one second heat source selected from a group comprising an oil heat exchanger, an engine jacket, a water jacket heat exchanger, a lower temperature intercooler, a higher temperature intercooler, or combinations thereof.

8. The recovery system of claim **7**, further comprising a partial evaporator; wherein the condenser is coupled to the oil heat exchanger, the engine jacket, the water jacket heat exchanger, the engine jacket, the lower temperature intercooler, the higher temperature intercooler, or combinations thereof through the partial evaporator configured to partially evaporate the second working fluid before entering the cascaded heat exchange unit.

9. The recovery system of claim **8**, further comprising one bypass unit configured to divert at least a portion of water to bypass the partial evaporator; wherein the one bypass unit comprises a control valve coupled to a bypass path.

10. The recovery system of claim **8**, further comprising one bypass unit configured to divert at least a portion of the second working fluid to bypass the partial evaporator, wherein the one bypass unit comprises a control valve coupled to a bypass path.

11. The recovery system of claim **1**, wherein the at least one bypass unit comprises a control valve, a three-way valve, pressure reduction valve, or combinations thereof coupled to a bypass path.

12. A waste heat recovery system including at least two integrated organic rankine cycle systems, the recovery system comprising:

a combustion engine comprising one heat source having an engine exhaust unit; and at least one other heat source selected from a group comprising an oil heat exchanger, an engine jacket, a water jacket heat exchanger, a lower temperature intercooler, a higher temperature intercooler, or combinations thereof;

a first organic rankine cycle system comprising a first evaporator and a first expander, wherein the first organic rankine cycle system is coupled to the engine exhaust unit and configured to circulate a first organic working fluid; wherein the first organic rankine system is configured to remove heat from the engine exhaust unit;

a second organic rankine cycle system comprising a second evaporator and a second expander; wherein the second organic rankine cycle system is coupled to the at least one other heat source selected from the group comprising the oil heat exchanger, the engine jacket, the water jacket heat exchanger, the lower temperature intercooler, the higher temperature intercooler, or combinations thereof; and configured to circulate a second organic working fluid, the one heat source comprising a higher temperature heat source than the at least one other heat source, wherein the second organic rankine cycle system is configured to remove heat from the at least one other heat source; and

a cascaded heat exchange unit, wherein the first and second organic working fluids are circulatable in heat exchange relationship through the cascaded heat exchange unit for condensation of the first organic working fluid in the first organic rankine cycle system and evaporation of the second organic working fluid in the second organic rankine cycle system;

at least one bypass unit configured to divert at least a portion of the first working fluid to bypass the first evaporator, the first expander, the cascaded heat exchange unit, or combinations thereof; at least a portion of the second working fluid to bypass the second expander, the cascaded heat exchange unit, or combinations thereof.

13. The recovery system of claim **12**, wherein the first evaporator is coupled to the engine exhaust unit via a thermal oil heat exchanger, exhaust economizer, or combinations thereof.

14. The recovery system of claim **13**, further comprising one bypass unit configured to divert at least a portion of thermal oil to bypass the first evaporator; wherein the one bypass unit comprises a control valve coupled to a bypass path.

15. The recovery system of claim **13**, further comprising one bypass unit configured to divert at least a portion of thermal oil to bypass the thermal oil heat exchanger; wherein the one bypass unit comprises a control valve coupled to a bypass path.

16. The recovery system of claim **12**, further comprising one bypass unit configured to divert at least a portion of engine exhaust gas to bypass the thermal oil heat exchanger; wherein the one bypass unit comprises a control valve coupled to a bypass path.

17. The recovery system of claim **12**, wherein the second rankine cycle system comprises a condenser coupled to the at least one other heat source selected from a group comprising an oil heat exchanger, an engine jacket, a water jacket heat exchanger, a lower temperature intercooler, a higher temperature intercooler, or combinations thereof.

18. The recovery system of claim **17**, further comprising a partial evaporator; wherein the condenser is coupled to the oil heat exchanger, the engine jacket, the water jacket heat exchanger, the engine jacket, the lower temperature intercooler, the higher temperature intercooler, or combinations thereof through the partial evaporator configured to partially evaporate the second working fluid before entering the cascaded heat exchange unit.

19. The recovery system of claim **18**, further comprising one bypass unit configured to divert at least a portion of water to bypass the partial evaporator; wherein the one bypass unit comprises a control valve coupled to a bypass path.

20. The recovery system of claim **18**, further comprising one bypass unit configured to divert at least a portion of the second working fluid to bypass the partial evaporator, wherein the one bypass unit comprises a control valve coupled to a bypass path.

21. The recovery system of claim **12**, wherein the at least one bypass unit comprises a control valve, a three-way valve, pressure reduction valve, or combinations thereof coupled to a bypass path.

22. A waste heat recovery system including at least two integrated rankine cycle systems, the recovery system comprising:

a heat generation system comprising at least two separate heat sources having different temperatures;

a first rankine cycle system comprising a first evaporator and a first expander, wherein the first rankine cycle system is coupled to a first heat source among the at least two separate heat sources and configured to circulate a first working fluid; wherein the first rankine system is configured to remove heat from the first heat source;

a second rankine cycle system comprising a second evaporator and a second expander; wherein the second rankine cycle system is coupled to at least one second heat source among the at least two separate heat sources and configured to circulate a second working fluid, the at least one second heat source comprising a lower temperature heat source than the first heat source, wherein the second rankine cycle system is configured to remove heat from the at least one second heat source;

a cascaded heat exchange unit, wherein the first and second working fluids are circulatable in heat exchange relationship through the cascaded heat exchange unit for condensation of the first working fluid in the first rankine cycle system and evaporation of the second working fluid in the second rankine cycle system; wherein the second rankine cycle is configured to preheat and/or partially evaporate the second working fluid before entering the cascaded heat exchange unit and

at least one bypass unit configured to divert at least a portion of the first working fluid to bypass the first evaporator, the first expander, the cascaded heat exchange unit, or combinations thereof; at least a portion of the second working fluid to bypass the second expander, the cascaded heat exchange unit, or combinations thereof.

23. The recovery system of claim **22**, wherein the second rankine cycle system comprises a condenser coupled to the at least one second heat source selected from a group comprising an oil heat exchanger, an engine jacket, a water jacket heat exchanger, a lower temperature intercooler, a higher temperature intercooler, or combinations thereof.

24. The recovery system of claim **23**, further comprising a partial evaporator; wherein the condenser is coupled to the oil heat exchanger, the engine jacket, the water jacket heat exchanger, the engine jacket, the lower temperature intercooler, the higher temperature intercooler, or combinations thereof through the partial evaporator configured to partially evaporate the second working fluid before entering the cascaded heat exchange unit.

25. The recovery system of claim **24**, further comprising one bypass unit configured to divert at least a portion of water to bypass the partial evaporator; wherein the one bypass unit comprises a control valve coupled to a bypass path.

26. The recovery system of claim **24**, further comprising one bypass unit configured to divert at least a portion of the second working fluid to bypass the partial evaporator, wherein the one bypass unit comprises a control valve coupled to a bypass path.

27. The recovery system of claim **22**, wherein the at least one bypass unit comprises a control valve, a three-way valve, pressure reduction valve, or combinations thereof coupled to a bypass path.

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