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(54) OIL REMOVAL FROM A TURBINE OF AN ORGANIC RANKINE CYCLE (ORC) SYSTEM

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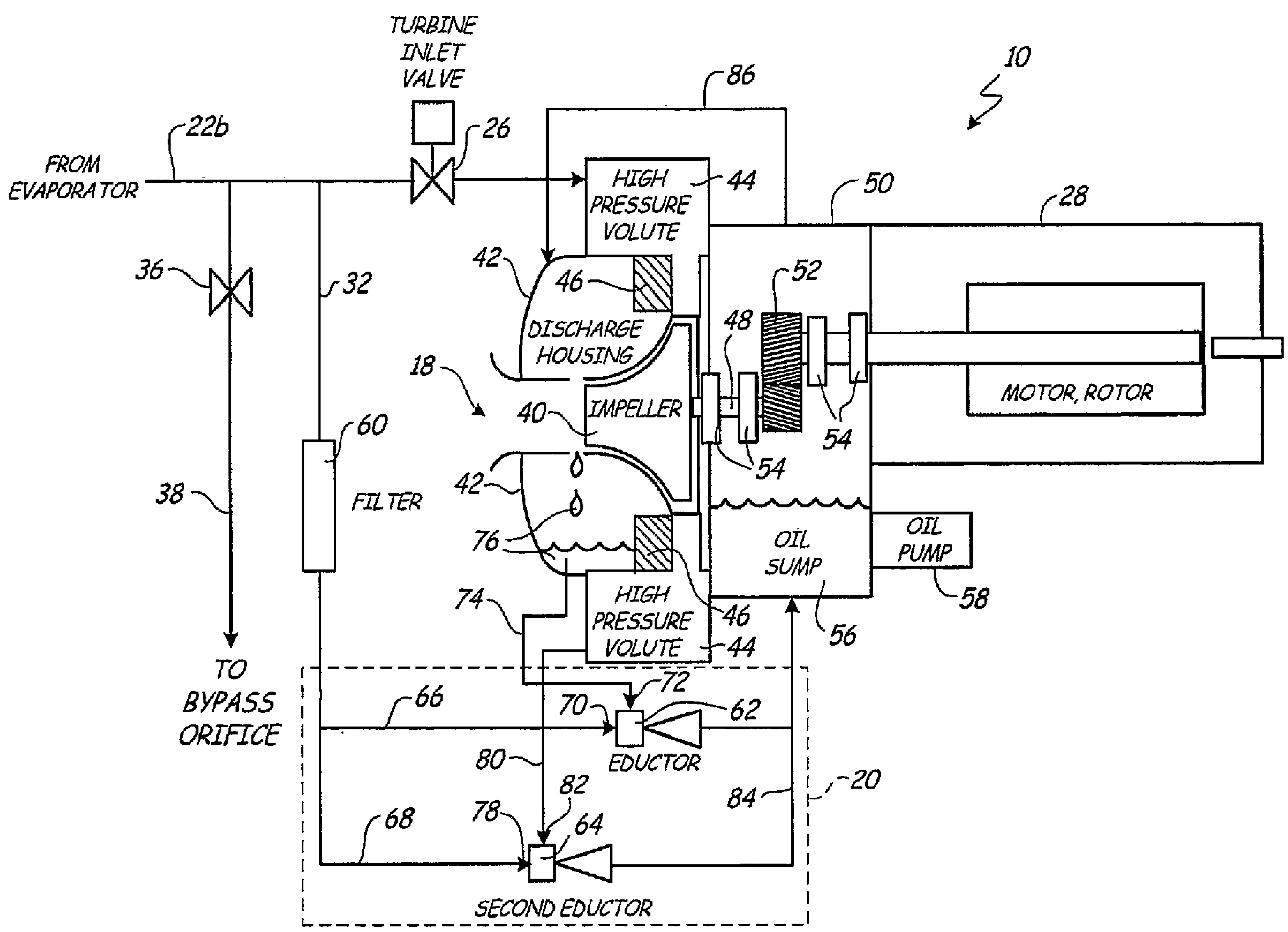
(57) **ABSTRACT**

A method and system for removing oil in an organic rankine cycle (ORC) system (**10**) is used to prevent failures in the ORC system (**10**), especially during startup. The ORC system (**10**) includes an evaporator, a turbine (**18**), a condenser and a pump, and is configured to circulate a refrigerant (**22**) through the ORC system (**10**). The oil-removal system is used to remove oil from certain areas of the turbine (**18**), and includes an eductor line (**32**) and an eductor system (**20**). The eductor line (**32**) is located upstream of the turbine (**18**) and configured to receive a portion of the refrigerant (**22*b***) exiting the evaporator. The eductor line (**32**) delivers the refrigerant (**22*b***) to an eductor system (**20**) configured to remove oil from inside the turbine (**18**) and deliver the oil to an oil sump (**58**).



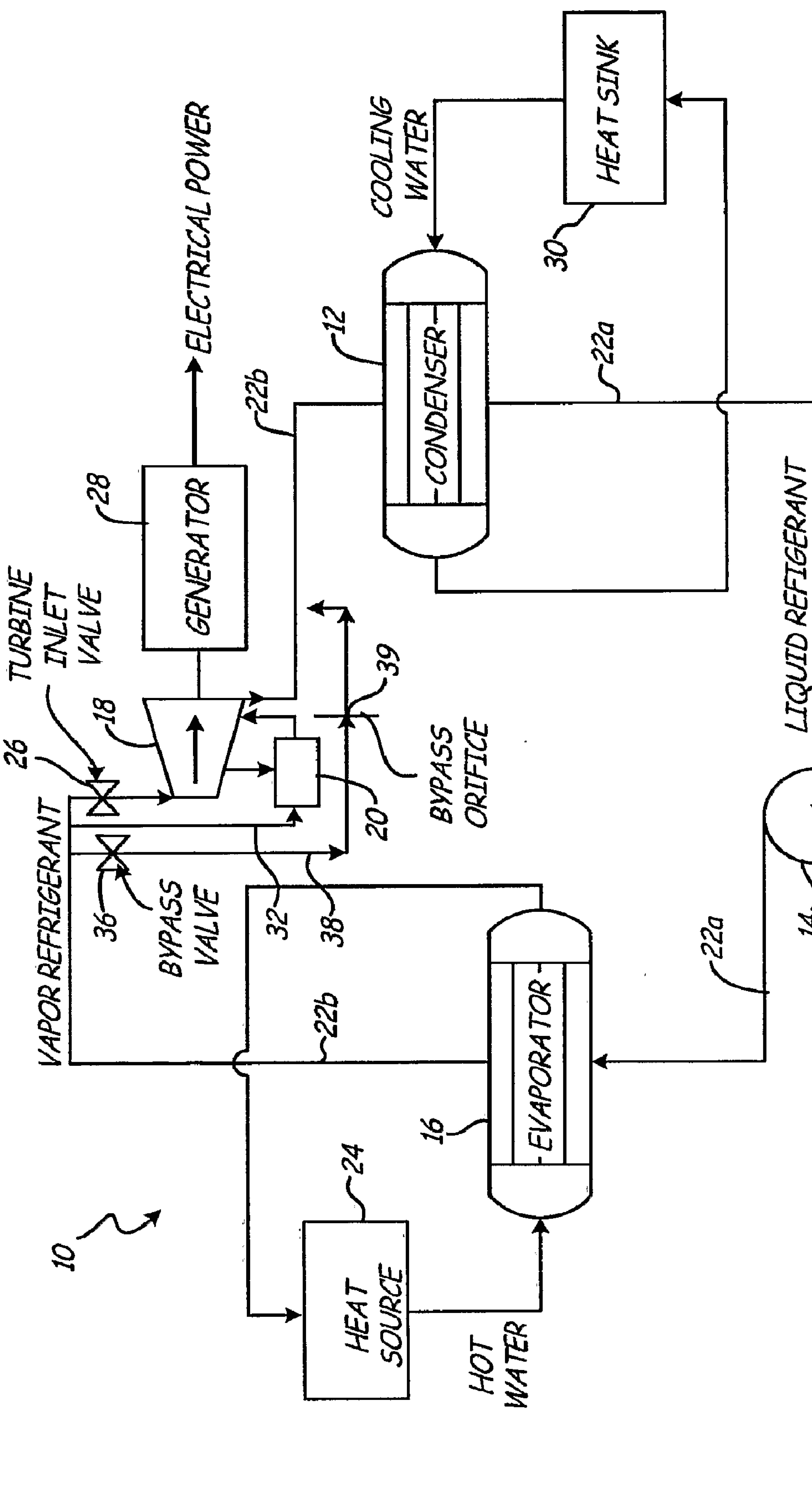

ELECTRICAL POWER
COOLING WATER
HEAT SINK
30
12
CONDENSER
22a
22b
28
GENERATOR
TURBINE INLET VALVE
26
18
39
BYPASS ORIFICE
20
LIQUID REFRIGERANT
PUMP
14
VAPOR REFRIGERANT
36
BYPASS VALVE
32
38
22a
22b
EVAPORATOR
16
24
HEAT SOURCE
HOT WATER
10

Fig. 1

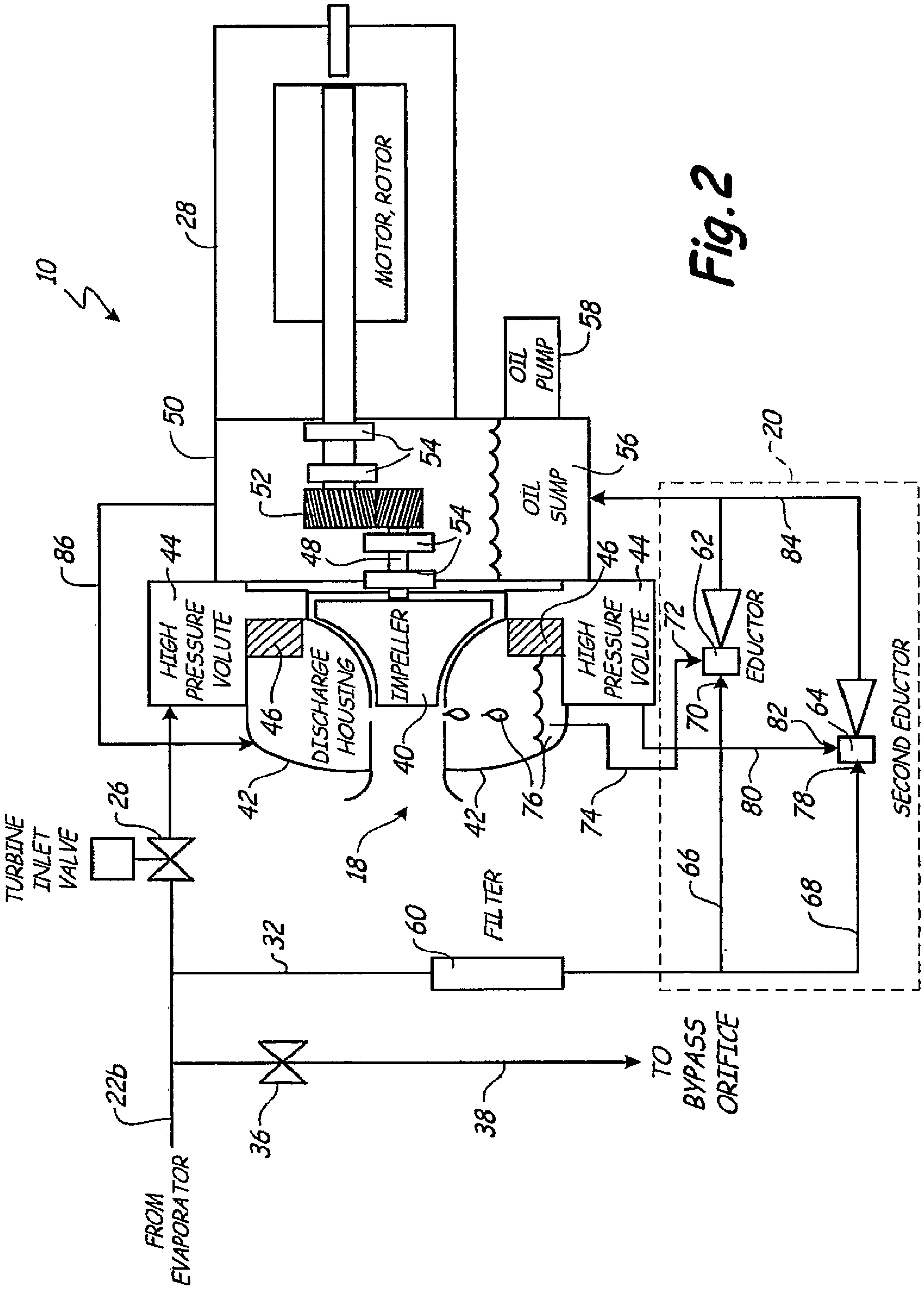

10
28
MOTOR, ROTOR
OIL PUMP
58
50
54
52
54
OIL SUMP
56
20
86
44
48
46
44
62
84
HIGH PRESSURE VOLUTE
IMPELLER
DISCHARGE HOUSING
46
HIGH PRESSURE VOLUTE
72
EDUCTOR
70
64
82
SECOND EDUCTOR
40
42
76
74
80
78
TURBINE INLET VALVE
26
18
42
66
68
FILTER
60
32
TO BYPASS ORIFICE
22b
36
38
FROM EVAPORATOR

Fig. 2

OIL REMOVAL FROM A TURBINE OF AN ORGANIC RANKINE CYCLE (ORC) SYSTEM

BACKGROUND

[0001] The present disclosure relates to an organic rankine cycle (ORC) system. More particularly, the present disclosure relates to an improved method and system for recovering oil from a turbine of an ORC system.

[0002] Rankine cycle systems are commonly used for generating electrical power. The rankine cycle system includes an evaporator or a boiler for evaporation of a motive fluid, a turbine that receives the vapor from the evaporator to drive a generator, a condenser for condensing the vapor, and a pump or other means for recycling the condensed fluid to the evaporator. The motive fluid in rankine cycle systems is often water, and the turbine is thus driven by steam. An organic rankine cycle (ORC) system operates similarly to a traditional rankine cycle, except that an ORC system uses an organic fluid, instead of water, as the motive fluid.

[0003] Oil may be used for lubrication in the ORC system, particularly inside the turbine. For example, oil provides lubrication for the bearings of the turbine. During operation of the ORC system, the oil may migrate to areas of the ORC system where the oil is not desired, such as an area surrounding an impeller of the turbine. During a startup of the ORC system, it may be difficult to recover the oil from these undesired areas. In some cases, the unrecoverable oil may result in failed startups of the ORC system.

[0004] There is a need for an improved method and system for removing the oil from the turbine during the startup of the ORC system.

SUMMARY

[0005] An oil-removal system is used in an organic rankine cycle (ORC) system to prevent failures, particularly during startup, by removing oil from inside a turbine of the ORC system. The oil-removal system includes an eductor line located upstream of the turbine and configured to receive a portion of a refrigerant exiting an evaporator of the ORC system. The eductor line delivers the refrigerant to an eductor system, which removes the oil from an area surrounding an impeller of the turbine and delivers the oil back to an oil sump.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. **1** is a schematic of an organic rankine cycle (ORC) system, including a turbine and an eductor system for removing oil from the turbine.

[0007] FIG. **2** is a schematic of the turbine and the eductor system of FIG. **1**.

DETAILED DESCRIPTION

[0008] An organic rankine cycle (ORC) system may be used to generate electrical power. Oil is used within the ORC system to provide lubrication for various pieces of equipment, particularly inside a turbine of the ORC system. As the ORC is operating, however, the oil may travel to other areas of the turbine where the oil is not needed, and in some cases, the oil may be destructive to some of the equipment. Moreover, when the system is starting up, if there is oil in certain areas of the turbine, such as the impeller, the oil may result in a system failure. This disclosure focuses on a method and system for effectively removing the oil from the turbine during a startup of the ORC system.

[0009] FIG. **1** is a schematic of ORC system **10**, which includes condenser **12**, pump **14**, evaporator **16**, turbine **18**, and eductor system **20** connected to turbine **18**. Refrigerant **22** circulates through system **10** and is used to generate electrical power. Liquid refrigerant **22***a* from condenser **12** passes through pump **14**, resulting in an increase in pressure. High pressure liquid refrigerant **22***a* enters evaporator **16**, which utilizes heat source **24** to vaporize refrigerant **22**. Heat source **24** may include, but is not limited to, any type of waste heat, including fuel cells, microturbines, and reciprocating engines, and other types of heat sources such as solar, geothermal or waste gas. Refrigerant **22** exiting evaporator **16** is a vaporized refrigerant (**22***b*), at which point it passes through turbine inlet valve **26** and into turbine **18**. Vaporized refrigerant **22***b* is used to drive turbine **18**, which in turn powers generator **28** such that generator **28** produces electrical power. Vaporized refrigerant **22***b* exiting turbine **18** is returned to condenser **12**, where it is condensed back to liquid refrigerant **22***a*. Heat sink **30** is used to provide cooling water to condenser **12**.

[0010] Eductor system **20** is connected to turbine **18** and is configured to remove oil from those areas of turbine **18** where it may commonly collect. As explained in more detail below in reference to FIG. **2**, eductor line **32** receives a portion of vaporized refrigerant **22***b* flowing from evaporator **16** and delivers refrigerant **22***b* to eductor system **20**.

[0011] As shown in FIG. **1**, ORC system **10** also includes bypass valve **36** and bypass line **38**, which may be used to prevent refrigerant **22***b* from passing through turbine **18** during a startup. During a startup of system **10**, turbine **18** temporarily runs in a bypass mode, at which time it does not receive any refrigerant, in order to reach the predetermined operating conditions (i.e. temperature and pressure) for turbine **18**. In that case, refrigerant **22***b* flows through bypass line **38** and is directed through bypass orifice **39** to increase a temperature of refrigerant **22***b*, and imitate operating conditions inside turbine **18**. After passing through bypass orifice **39**, refrigerant **22***b* is directed to condenser **12**. In some embodiments, bypass valve **36** is closed when turbine inlet valve **26** is open, and vice versa.

[0012] FIG. **2** is a schematic of a portion of ORC system **10** from FIG. **1**, including turbine **18**, eductor system **20**, eductor line **32**, turbine inlet valve **26**, generator **28**, bypass valve **36**, and bypass line **38**. Turbine **18** includes impeller **40**, discharge housing **42**, and high pressure volute **44**. (Volute **44** is designated as "high pressure volute" since the volute is at high pressure when turbine **18** is operating. However, volute **44** is at low pressure when system **10** and turbine **18** are in the bypass mode during startup.) During an operational mode of turbine **18**, vaporized refrigerant **22***b* (from evaporator **16**) passes through inlet valve **26** into high pressure volute **44**, and then through nozzles **46**, which impart motive force to impeller **40** to drive shaft **48** inside gear box **50**. Gears **52** connect drive shaft **48** to generator **28**, which uses the shaft energy to generate electrical power. Gear box **50** also includes bearings **54**, oil sump **56**, and oil pump **58**.

[0013] Eductor line **32** is located upstream of turbine inlet valve **26**, and is configured to receive a portion of vaporized refrigerant **22***b* exiting evaporator **16** (and flowing to turbine **18**). Line **32** then delivers refrigerant **22***b* to eductor system **20**, which is configured to remove liquid (primarily oil) from turbine **18**. In the embodiment shown in FIG. **2**, eductor line

32 is located downstream of bypass line 36; in alternative embodiments, eductor line 32 may be located upstream of bypass line 36.

[0014] By placing eductor line 32 upstream of turbine inlet valve 26, eductor line 32 is able to continuously supply refrigerant 22 to eductor system 20 whenever refrigerant 22 is circulating through system 10, regardless of the mode of turbine 18. Even if turbine 18 is in a bypass mode during startup and refrigerant 22 from evaporator 16 is being diverted through bypass line 36, refrigerant 22 may still flow to eductor system 20.

[0015] In other designs of an ORC system, the eductor line may commonly be connected to the turbine such that the refrigerant source for the eductor system is delivered from the turbine. For example, the eductor line may be connected to the high pressure volute such that the eductor system uses refrigerant that was flowing through the high pressure volute of the turbine. In those designs, however, the eductor system is only operable when refrigerant from the evaporator is flowing through the turbine. As explained above in reference to FIG. 1, during a startup of the system, the vaporized refrigerant from the evaporator is prevented from flowing through the turbine. The refrigerant instead flows through the bypass line, and then to the condenser. Thus, when the eductor system is dependent on refrigerant from the turbine, it is not feasible to remove the oil from the turbine during a bypass or startup mode of the turbine.

[0016] The startup mode, however, may be an important time for removing oil from those areas of the turbine surrounding the impeller (i.e. the high pressure volute and discharge housing). Some of the equipment inside the turbine may be damaged if the turbine starts up with oil in these areas. Moreover, during operation and particularly during shut down of the ORC system, the oil inside the turbine commonly migrates to the discharge housing and the high pressure volute.

[0017] Again, because eductor line 32 of system 10 is located upstream of turbine inlet valve 26 and receives refrigerant 22*b* directly from evaporator 16, eductor system 20 is able to remove oil from turbine 18 during all modes of running system 10. Eductor line 32 receives a small portion of refrigerant 22 from evaporator 16 and thus has a minimal impact on operation and efficiency of turbine 18. For example, in one embodiment, less than one weight percent of refrigerant 22 from evaporator 16 flows to line 32; and in a preferred embodiment, approximately 0.2 weight percent flows to line 32. In the embodiment shown in FIG. 2, eductor line 32 does not include a valve since line 32 is configured to receive refrigerant 22 whenever refrigerant 22 is flowing through ORC system 10. It is recognized that eductor line 32 may include a control valve. As shown in FIG. 2, eductor line 32 may include filter 60, which is configured to remove particulates from refrigerant 22.

[0018] In the embodiment shown in FIG. 2, eductor system 20 includes first eductor 62 and second eductor 64, which operate as venturi devices, and each includes a primary flow inlet and a secondary flow inlet. In each eductor, high pressure refrigerant from evaporator 16 flows through the primary flow inlet, creating enough suction force to draw liquid out of turbine 18.

[0019] Eductor system 20 also includes first line 66 and second line 68, both of which are connected to eductor line 32. First line 66 is configured to deliver refrigerant 22 to primary flow inlet 70 of first eductor 62. Secondary flow inlet 72 of first eductor 62 is connected to line 74 and delivers oil 76, which is removed from discharge housing 42 of turbine 18, through first eductor 62. (It is recognized that although the liquid sucked out of discharge housing 42 is primarily oil, the liquid may contain some amount of refrigerant.) Second line 68 is configured to deliver refrigerant 22 to primary flow inlet 78 of second eductor 64. Line 80 is connected to secondary flow inlet 82 of second eductor 64 and delivers liquid removed from high pressure volute 44 of turbine 18. Liquid extracted from high pressure volute 44 is mostly oil; however, the liquid may include some of the refrigerant flowing inside turbine 18. After flowing through eductors 62 and 64, the refrigerant and the oil collectively travel to oil sump 56 through line 84. The refrigerant, which is vapor, may be recycled back to discharge housing 42 from sump 56 via line 86.

[0020] Although eductor system 20, as shown in FIG. 2, includes two eductors, it is recognized that eductor system 20 may operate with only first eductor 62. Because eductor line 32 is located upstream of turbine inlet valve 26, eductor line 32 may deliver refrigerant to first eductor 62 at all times. As such, first eductor 62 is effective at removing oil from turbine 18, particularly during a startup of turbine 18. By removing oil from discharge housing 42 prior to starting up turbine 18, system 10 exhibits a decrease in a number of failed startups, as compared to an ORC system in which the eductor system is not operable during startup because it is dependent on refrigerant from the turbine.

[0021] Although second eductor 64 is not required, it is recognized that using second eductor 64, in combination with first eductor 62 and eductor line 32, further increases the effectiveness of system 10 for removing oil from turbine 18. As explained above, oil may collect in both discharge housing 42 and high pressure volute 44. Second eductor 64 is able to remove oil from high pressure volute 44, where it commonly collects once the oil is separated from the vaporized refrigerant inside volute 44. Using a two-eductor system improves overall recovery of the oil because the oil may be removed from both areas around impeller 40 where it can accumulate.

[0022] Although this disclosure focuses on the use of eductor line 32 and eductor system 20 during a startup of turbine 18, it is recognized that the oil removal system described herein is used to remove oil from the discharge housing and the high pressure volute at any point that ORC system is running. This includes an operational mode of the turbine when refrigerant from the evaporator is flowing through the turbine.

[0023] Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

1. An oil-removal system for preventing failures in an organic rankine cycle (ORC) system having an evaporator, a turbine, a condenser and a pump, and configured to circulate a refrigerant through the ORC system, the oil-removal system comprising:

an eductor line located upstream of the turbine and configured to receive a portion of the refrigerant exiting the evaporator; and

an eductor system configured to receive the refrigerant from the eductor line and extract liquid out of the turbine.

2. The oil-removal system of claim **1** wherein the eductor system comprises:

a first eductor configured to receive the refrigerant from the eductor line and extract liquid out of a discharge housing of the turbine.

3. The oil-removal system of claim **2** wherein the eductor system comprises:

a second eductor configured to receive the refrigerant from the eductor line and extract liquid out of a high pressure volute of the turbine.

4. The oil-removal system of claim **1** further comprising:

an oil sump configured to receive the liquid extracted from the eductor system.

5. The oil-removal system of claim **1** wherein the refrigerant exiting the evaporator is a vapor.

6. The oil-removal system of claim **1** wherein the refrigerant exiting the evaporator includes oil.

7. The oil-removal system of claim **1** wherein the liquid extracted from the turbine includes oil, refrigerant, and combinations thereof.

8. The oil-removal system of claim **1** wherein the eductor line comprises a filter configured to remove particulates from the refrigerant.

9. An organic rankine cycle (ORC) system for generating power, the ORC system comprising:

a condenser configured to condense a vaporized refrigerant;

a pump configured to increase a pressure of the condensed refrigerant;

an evaporator configured to receive the condensed refrigerant and vaporize the refrigerant;

a turbine configured to receive the vaporized refrigerant and generate power, wherein the turbine includes an impeller, a discharge housing, a high pressure volute, and an oil sump;

an inlet valve configured to control a delivery of refrigerant from the evaporator to the turbine;

a bypass valve configured to prevent the refrigerant from flowing through the turbine during a startup of the turbine, and divert the refrigerant to the condenser;

an eductor line located upstream of the inlet valve and configured to receive a portion of the refrigerant from the evaporator; and

an eductor system configured to receive the refrigerant from the eductor line and extract liquid out of the turbine.

10. The ORC system of claim **9** wherein the eductor system comprises:

a first eductor configured to receive refrigerant from the eductor line and suck liquid out of the discharge housing of the turbine.

11. The ORC system of claim **10** wherein the eductor system comprises:

a second eductor configured to receive refrigerant from the eductor line and suck liquid out of the high pressure volute of the turbine.

12. The ORC system of claim **9** wherein the inlet valve is in a closed position when the bypass valve is in an open position.

13. The ORC system of claim **9** wherein a weight of the refrigerant received by the eductor line is less than one percent of a total weight of refrigerant from the evaporator.

14. The ORC system of claim **9** wherein the eductor line includes a filter configured to remove particulates from the refrigerant.

15. A method of operating an organic rankine cycle (ORC) system having an evaporator, a turbine, and a refrigerant configured to circulate through the evaporator and the turbine, the method comprising:

preventing the refrigerant exiting the evaporator from passing through the turbine during a startup of the turbine;

delivering the refrigerant from the evaporator to a bypass line configured to deliver the refrigerant to the condenser during a startup of the turbine;

delivering a portion of the refrigerant from the evaporator to an eductor system; and

extracting liquid out of the turbine using the eductor system.

16. The method of claim **15** wherein delivering a portion of the refrigerant from the evaporator to the eductor system includes:

delivering a first portion of the refrigerant to a first eductor, wherein the first eductor is configured to extract liquid from a discharge housing of the turbine; and

delivering a second portion of the refrigerant to a second eductor, wherein the second eductor is configured to extract liquid from a high pressure volute of the turbine.

17. The method of claim **15** wherein delivering a portion of the refrigerant from the evaporator to an eductor system is performed by an eductor line located upstream of the turbine.

18. The method of claim **15** wherein the portion of the refrigerant delivered to the eductor system is less than one percent of a total weight of refrigerant from the evaporator.

19. The method of claim **15** further comprising:

delivering the liquid extracted out of the turbine to an oil sump of the turbine.

20. The method of claim **15** wherein the liquid extracted from the turbine includes at least one of oil, refrigerant, and combinations thereof.

* * * * *