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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 (22b) exiting the evaporator. The eductor line (32) delivers the refrigerant (22b) to an eductor system (20) configured to remove oil from inside the turbine (18) and deliver the oil to an oil sump (58).

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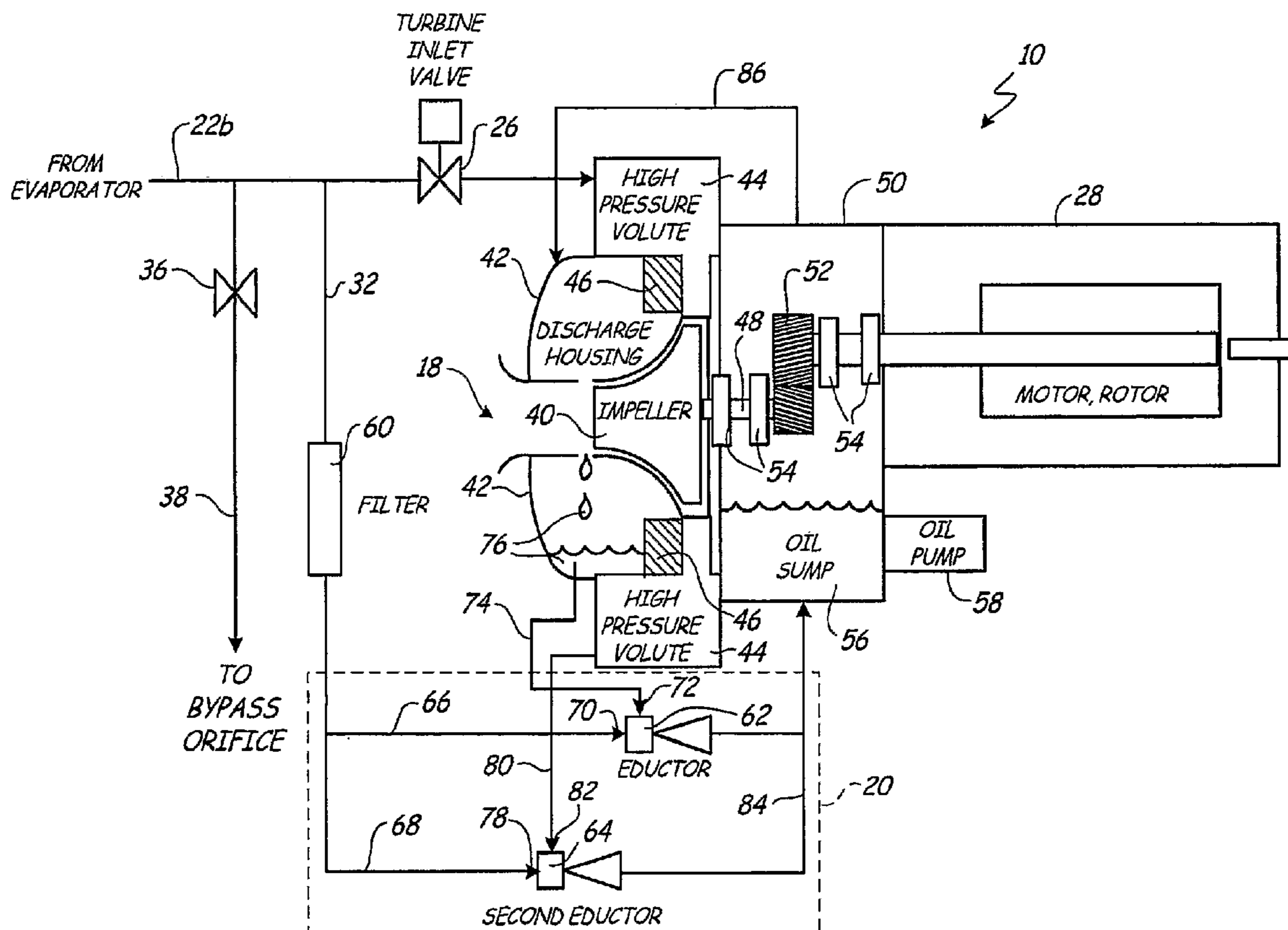
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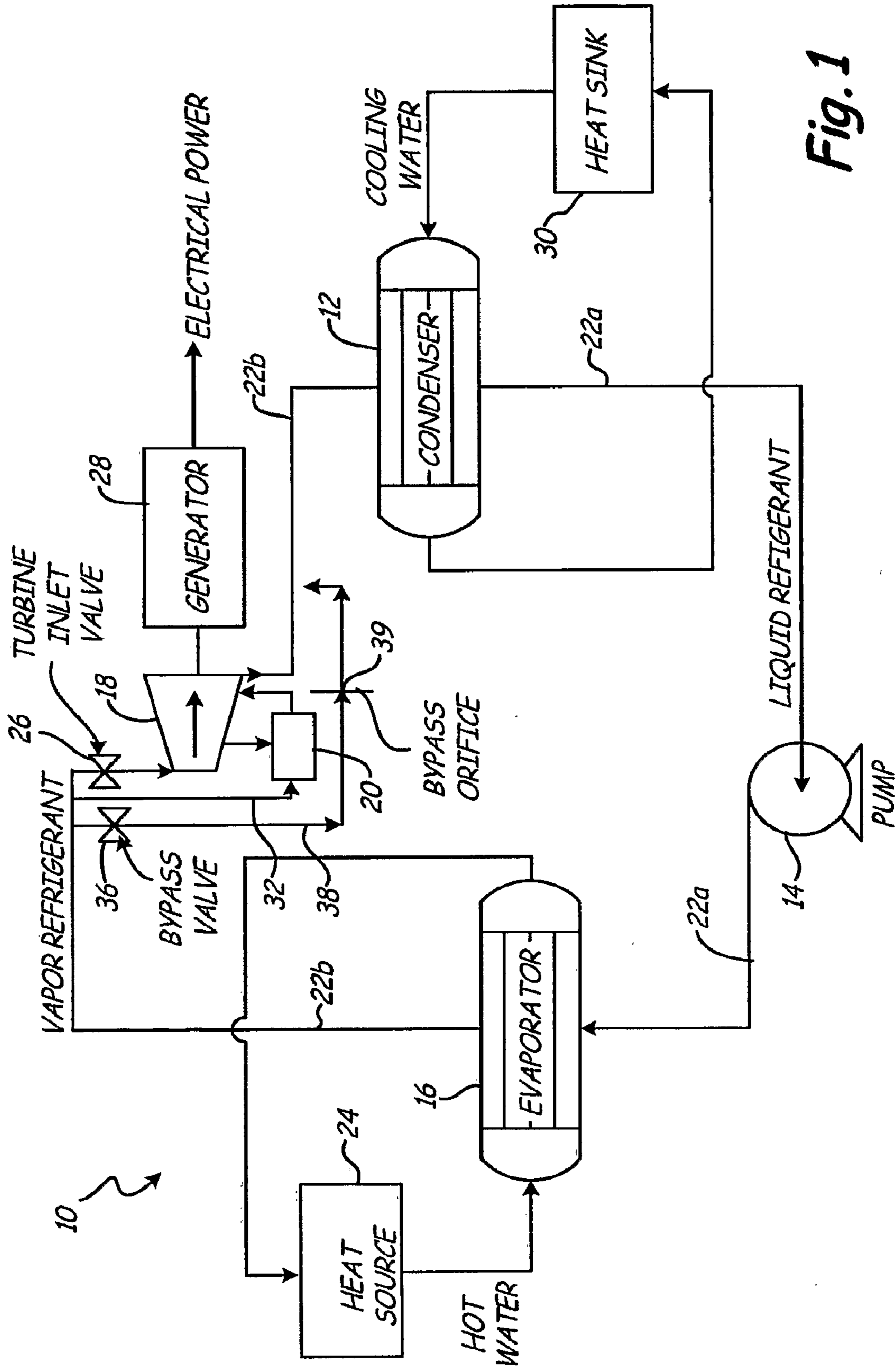
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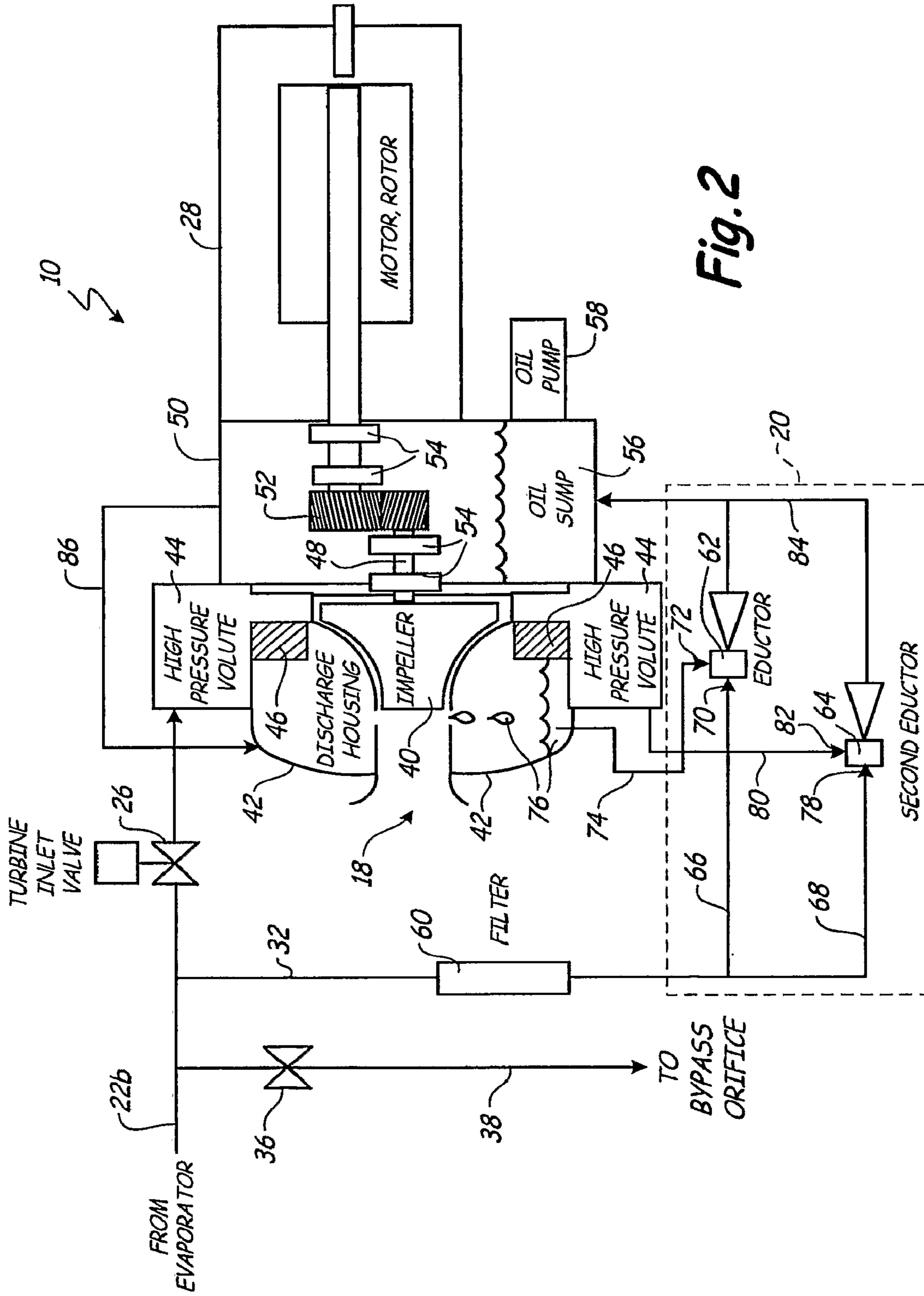


Fig. 2

## 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 22a from condenser 12 passes through pump 14, resulting in an increase in pressure. High pressure liquid refrigerant 22a 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 (22b), at which point it passes through turbine inlet valve 26 and into turbine 18. Vaporized refrigerant 22b is used to drive turbine 18, which in turn powers generator 28 such that generator 28 produces electrical power. Vaporized refrigerant 22b exiting turbine 18 is returned to condenser 12, where it is condensed back to liquid refrigerant 22a. 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 22b flowing from evaporator 16 and delivers refrigerant 22b 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 22b 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 22b flows through bypass line 38 and is directed through bypass orifice 39 to increase a temperature of refrigerant 22b, and imitate operating conditions inside turbine 18. After passing through bypass orifice 39, refrigerant 22b 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 22b (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 22b exiting evaporator 16 (and flowing to turbine 18). Line 32 then delivers refrigerant 22b 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 **22b** 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.

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