

S P E C I F I C A T I O N
WASTE HEAT RECOVERY GENERATOR
P R I O R I T Y S T A T E M E N T

[0001] This application claims priority to a U.S. Non-Provisional Application filed on April 19, 2006 entitled "Waste Heat Recovery Generator," U.S. Provisional Application Serial No. 60/673,542, entitled "Waste Heat Recovery Generator," filed on April 20, 2005 and to U.S. Provisional Application Serial No. 60/673,543, entitled "Waste Heat Recovery Generator," filed on April 20, 2005. The disclosures of each patent application are incorporated by reference herein in their entirety.

B A C K G R O U N D

[0002] The conversion of fuels into electricity has long been the focus of engineers. The supply of the fuel to the generation site as well as the reliability and cost of the supply has factored into the engineering decision process. One area of energy conversion for electrical supply has been to utilize currently converted thermal energy from fuel energy of an unrelated process into electrical energy. Another more specific area of energy conversion is the recovery of discarded thermal energy into electrical energy, i.e., waste heat recovery. With ever increasing electrical power costs for commercial and residential electrical power, customers are expanding the search for alternative sources of reliable electrical power. The increasing need for electricity in areas with limited access to electrical power or even high cost electrical power has fertilized the field of waste heat recovery technologies.

[0003] The thrust of waste heat recovery technology is to make use of thermal energy normally discarded from a primary power conversion process. The discarded thermal energy, i.e., waste heat, can be harnessed to drive additional thermo-fluid processes that can yield additional energy, i.e., electricity.

[0004] The prior art has developed many systems that can convert the waste heat into electrical power. Conventional waste heat systems are designed to recover waste heat and generate electrical power.

[0005] Referring to Prior Art FIG. 1, the prior art waste heat recovery system directs a supply of waste heat measured at temperatures between 300°F to 800°F from a heat source to an evaporator (see numeral 1). The waste heat is transferred to a working fluid in the evaporator. The working fluid is evaporated; changes from a liquid to a vapor, in the evaporator and expanded through a turbine (see numeral 2). The expansion of the working fluid through the

turbine drives the turbine. The turbine, in turn, drives an electric generator coupled to the turbine. The generator produces electrical power. The working fluid flows to a condenser and changes phase from vapor to a liquid (see numeral 3). The liquid working fluid is then pumped back to the evaporator and begins the cycle again (see numeral 4). The above described system employs the closed-loop Rankin cycle to produce electricity from a thermal energy source, such as waste heat. The waste heat can be recovered from engines, gas turbines, gas flares in landfills, industrial manufacturing processes that continuously produce thermal energy, incinerators, boilers, geothermal wells, bio-gas sources, and the like.

[0006] The above prior art example waste heat recovery system is large and requires costly turbine-generator sets. The turbine-generator sets are complex, expensive and require considerable maintenance expertise in order to reliably function continuously. These prior art systems also require high temperature heat of above 300°F.

[0007] What is needed in the art is a waste heat recovery electrical generator system that includes simple and reliable cost efficient components at low cost and high efficiency that can be scaled for residential to industrial use.

SUMMARY

[0008] The following presents a simplified summary of the present invention in order to provide a basic understanding of some aspects of the present invention. This summary is not an extensive overview of the present invention. It is not intended to identify key or critical elements of the present invention or to delineate the scope of the present invention. Its sole purpose is to present some concepts of the present invention in a simplified form as a prelude to the more detailed description that is presented herein.

[0009] A simple, reliable, high efficiency low cost waste recovery generator system is disclosed. The system uses low temperature waste heat of about 140°F to about 300°F. The system is easy to install and requires little maintenance. The system operates at low revolutions per minute (rpms), from about 800 rpms to about 10,000 rpms. The system can control vapor wetness through sensors connected to a microprocessor. The microprocessor controls the speed of the refrigerant feed pump using a VFD controller and can be scaled for residential to industrial use.

[0010] A low grade waste heat recovery generator system is presented. The system comprises an expander generator set having a compressor rotatably coupled to a generator. The compressor rotates in a reverse direction to operate as an expander. The system also comprises a

condenser fluidly coupled to the expander generator set, a refrigerant pump fluidly coupled to the condenser, an evaporator fluidly coupled to the refrigerant pump and the expander generator set, and a working fluid configured to flow from the evaporator to the expander generator set, to the condenser, and to the refrigerant pump in a closed loop Organic Rankin Cycle. The working fluid is heated to a temperature of about 140°F to about 300°F.

[0011] A method of operating a waste heat recovery generator system to generate electrical power from low grade waste heat is disclosed. The method comprises transferring thermal energy from a waste heat source to a working fluid in an evaporator. The working fluid is heated to a temperature of about 140°F to about 300°F. The method also comprises expanding the working fluid through an expander generator set fluidly coupled to the evaporator. The expander generator set having a compressor rotatably coupled to a generator, in which the compressor rotates in a reverse direction to operate as an expander. The method also comprises rotating the expander to generate the electrical power in the generator and condensing the working fluid in a condenser fluidly coupled to the expander generator set. The method also comprises flowing the working fluid to a refrigerant pump fluidly coupled to the condenser and pumping the working fluid to the evaporator fluidly coupled to the refrigerant pump in a closed loop Organic Rankin Cycle.

BRIEF DESCRIPTION OF FIGURES

[0012] Referring now to the figures, wherein like elements are numbered alike:

[0013] FIG. 1 is an illustration of a prior art waste heat recovery system;

[0014] FIG. 2 is an illustration of an exemplary waste heat recovery generator system;

[0015] FIG. 3 is an illustration of an exemplary waste heat recovery generator system;

[0016] FIG. 4 is an illustration of an exemplary scroll compressor;

[0017] FIG. 5 is an illustration of an exemplary single screw compressor; and

[0018] FIG. 6 is an illustration of an exemplary double screw compressor.

DETAILED DESCRIPTION

[0019] Persons of ordinary skill in the art will realize that the following disclosure is illustrative only and not in any way limiting. Other embodiments of the invention will readily suggest themselves to such skilled persons having the benefit of this disclosure.

[0020] The disclosure describes an exemplary waste heat recovery generator system. The waste heat recovery generator system includes a cabinet that can be placed onsite and coupled to a waste heat source. A generator can mount directly in the cabinet. The generator cabinet contains an expander-generator expander set fluidly coupled to a condenser. The expander and condenser use a working fluid. The generator can also include a forced convection unit (i.e., numeral 72 in FIG. 3) fluidly coupled to the condenser for forced convective cooling of the condenser heat exchanger. The expander and condenser are fluidly coupled to an evaporator and a working fluid collector respectively. The evaporator and the working fluid collector are located in the cabinet. The evaporator is thermally coupled to the waste heat source. The waste heat is thermally transferred to the working fluid in the evaporator. The evaporated working fluid is expanded through the expander thereby rotating the generator. The expander drives the generator and generates electricity. The working fluid is condensed in the condenser and returned by gravity to the working fluid collector in liquid phase and is delivered and metered to the evaporator. The expander can be a single screw compressor, a double screw compressor, or a scroll compressor modified to run in reverse, as described further herein.

[0021] Referring to FIGS. 2 and 3, exemplary waste heat recovery generator systems 10 are illustrated. In FIG. 2, the waste heat recovery generator system 10 comprises a cabinet 12 mounted on top of a recovery cabinet 14. The waste heat recovery generator system 10 inputs waste heat and ambient air and outputs warm air and electrical power. The cabinet 12 includes an enclosure 16 that houses and supports the components of the cabinet 12. A scroll compressor running in reverse becomes an expander generator set 18 and is mounted in the cabinet 12. The expander generator set 18 includes an expander and a generator.

[0022] Waste heat 34 is controlled through a refrigerant feed pump (not shown), which can control vapor wetness through at least one sensor (not shown) connected to at least one microprocessor (not shown). The microprocessor (not shown) controls the speed of the refrigerant pump (not shown) using a variable frequency drive (VFD) controller (not shown). The waste heat 34 is directed to an evaporator 30 located in the recovery cabinet 14. Waste heat 34 is a term that generally covers various sources of thermal energy 32 in a transfer medium (such as a fluid, a hot gas, hot water, and the like). The waste heat 34 can be supplied from a wide variety of sources including but not limited to: internal combustion engines, gas turbines, gas flares in landfills, industrial manufacturing processes that continuously produce thermal energy, incinerators, boilers, water heaters, geothermal wells, bio-gas sources, and the like. The waste heat recovery generator system 10 of the present invention can convert low temperature

waste heat 34 (i.e., waste heat at temperatures as low as about 140°F to about 300°F) into usable mechanical energy for conversion to electricity.

[0023] The evaporator 30 exchanges the thermal energy 32 from the waste heat 34 to the working fluid 20. The evaporator 30 can be any variety of heat exchanger 36 and fashioned to operate with the waste heat 34. For example, if the waste heat 34 is in the form of an internal combustion engine exhaust, the heat exchanger 36 can comprise a gas heat exchanger. Intermediate heat exchangers (not shown) can be employed to preheat the working fluid 20 prior to entering the evaporator.

[0024] The working fluid 20 heats in the evaporator 30 and changes phase from a liquid to a vapor or a gas. The working fluid 20 can be any refrigerant (e.g., Honeywell refrigerant R-124 and R-245) compatible with the expander. The working fluid 20 having gained the thermal energy 32 and having reached a higher energy state (i.e., vapor or gas), flows from the evaporator 30 to the expander generator set 18 and expands through the expander transferring the higher thermal energy into mechanical energy (or mechanical rotation). The working fluid 20 expands through the expander spinning the generator and produces electricity. The generator is driven by the expander and rotates. By rotating the generator, electrical power is created. Although not specifically shown, the generator may run in parallel with the electrical grid, or run standalone. The generator can be electrically coupled to an electrical power supply and peripheral electronics to provide additional electrical power for use on-site or sent to the electrical utility grid.

[0025] As the working fluid 20 leaves the expander, the working fluid 20 flows to the condenser 22. The condenser 22 is fluidly coupled to the expander of the expander generator set 18. The condenser 22 has condenser plates 24 arranged within the generator cabinet 12, such that cooling air 26 can flow over the condenser plates 24 removing thermal energy and discharging the thermal energy from the generator cabinet 12. In the exemplary embodiment illustrated, the condensers 22 are arranged along the enclosure 16 in a vertical orientation. Incorporating a means for convection 28 (e.g., a fan) can enhance the cooling ability of the condenser 22. The fan 28 can draw cooling air 26 across the condenser plates 24 to provide a forced convective air current through the generator cabinet enclosure 16. The fan 28 can also function to discharge the heated cooling air to the atmosphere. The condensers 22 can be any variety of condensers including, but not limited to, water-cooled, plate, tube and shell, tube and fin, and the like.

[0026] In the condenser 22, the working fluid 50 is returned to a liquid state and flows to a working fluid receiver 38. The working fluid receiver 38 includes at least one collector container 40 configured to contain the liquid working fluid 20. In one embodiment, at least one three-way valve 42 is coupled to the collector container 40 inlet, collector container 40 outlet and a working fluid conduit 43.

[0027] In operation, the waste heat recovery generator system 10 converts the thermal energy 32 supplied from a source of waste heat 34 into mechanical energy and then into electrical energy. The working fluid 20 flows through the waste heat recovery generator system 10 in a closed-loop Organic Rankin Cycle (ORC) system. The working fluid 20 gains thermal energy 32 in the evaporator 30 and undergoes a phase change from liquid to vapor (or gas). The working fluid 20 expands through the expander, which transforms the thermal energy into mechanical energy. The mechanical energy is converted into electrical energy by the expander generator set 18. The working fluid 20 flows to the condenser 22 and again changes phase from a vapor (or a gas) back to a liquid. The liquid working fluid 20 flows to the working fluid collector 38 and is retained as a supply of liquid working fluid 20 for the operation of the waste heat recovery generator system 10.

[0028] In another embodiment presented in FIG. 3, waste heat 44 is directed through piping 46 to an evaporator 48 of the waste heat recovery generator system 10. As indicated above, waste heat 44 is a term that generally covers various sources of thermal energy in a transfer medium (such as a fluid, a hot gas, hot water, and the like). The waste heat 44 can be supplied from a wide variety of sources including but not limited to: internal combustion engines, gas turbines, gas flares in landfills, industrial manufacturing processes that continuously produce thermal energy, incinerators, boilers, water heaters, geothermal wells, bio-gas sources, and the like. The waste heat recovery generator system 10 of the present invention can convert low temperature waste heat 44 (i.e., waste heat at temperatures as low as about 140°F to about 300°F) into usable mechanical energy for conversion to electricity.

[0029] A working fluid 50 is pumped via a high pressure refrigerant pump 52. The refrigerant pump 52 can control vapor wetness of the working fluid 50 utilizing at least one sensor (not shown) connected to at least one microprocessor (not shown), which controls the speed of the refrigerant pump 52. The working fluid 52 is directed to the evaporator 48. The evaporator 48 transfers the thermal energy from waste heat 44 to the working fluid 50. In the preheater 54, the working fluid 50 is preheated to a temperature of about 180°F; the resulting working fluid 50 is directed to the evaporator 48. In the evaporator 48, the working fluid 50 is heated to a

temperature of about 300°F. The evaporator 48 transfers thermal energy from the waste heat 44 to the working fluid 50. The evaporator 48 can be any variety of heat exchanger and fashioned to operate with the waste heat 44, including, but not limited to, plate, tube and shell, tube and fin, and the like.

[0030] The heated working fluid 50 changes phase from a liquid to a vapor or a gas, preferably, a high pressure gas. The working fluid 50 then flows to the expander 56. The working fluid 50 expands through the expander 56 transferring the thermal energy into mechanical energy. The expander 56 can be a single screw compressor, a scroll compressor or a double screw compressor as illustrated in FIGS. 4, 5, and 6. In the present invention, the single screw compressor, the scroll compressor or the double screw compressor are operated in reverse in order to become an expander 56. In FIG. 4, a scroll compressor type expander 74 uses the working fluid 50 to create mechanical rotation. The working fluid 50 expands through the scroll compressor 74 in reverse, and transfers the mechanical energy to the generator also creating mechanical energy. In FIG. 5, a single screw compressor type expander 76 also uses the working fluid 50 to create mechanical rotation. The working fluid 50 expands through the single screw compressor 76 in reverse, and transfers the mechanical energy to the generator also creating mechanical energy. In FIG. 6, a double screw compressor type expander 78 also uses the working fluid 50 to create mechanical rotation. The working fluid 50 expands through the double screw compressor 78 in reverse, creating mechanical energy, which is transferred to the generator.

[0031] The expander 56 is mechanically coupled to a generator 58. The expander 56 creates mechanical rotation which is used by the generator 58 to generate electricity. The working fluid 50 expands through the expander 56 spinning the generator 58 to the generate electricity. Although not specifically shown, the generator 58 may run in parallel with the electricity grid, or run standalone. The generator 58 can be electrically coupled to an electrical power supply and peripheral electronics to condition the electrical power for use on-site or in the electrical utility grid.

[0032] Upon exiting the expander 56, the working fluid 50 has been converted to a low pressure gas that flows to the condenser 60 where it is cooled back to a liquid state and then flows by gravity to a receiver tank 62. Utilizing a refrigerant can enhance the cooling capabilities of the condenser 60. The receiver tank 62 feeds the liquid to the high pressure refrigerant pump 52. This is a closed loop ORC system. There is a modulating control valve 64 on a bypass/equalization line for working fluid 50 flow rate control. Several three-way valves 66 are

coupled throughout the system to control the flow through the system. Additionally, a safety bypass valve and safety solenoid 68 can be installed in the system.

[0033] In operation, the waste heat recovery generator system 10 converts the thermal energy supplied from a source of waste heat 44 into mechanical energy and then into electrical energy. The working fluid 50 flows through the waste heat recovery generator system 10 through a working fluid conduit 70 in a closed-loop ORC system. The working fluid 50 gains thermal energy in the preheater 54 and the evaporator 48 and undergoes a phase change from a liquid to a vapor or a gas. The working fluid 50 expands through the expander 56 and transforms the thermal energy into mechanical energy. The mechanical energy is converted into electrical energy by the generator 58. The working fluid 50 flows to the condenser 60 and changes phase again from a vapor or a gas back to a liquid. The liquid working fluid 50 flows to the working fluid collector 62 and is retained for a supply of liquid working fluid 50 for the continuation of the cycle in the waste heat recovery generator system 10.

[0034] In each of these embodiments, the expander 56 is created by operating the specific type of compressor in reverse. A conventional exemplary scroll compressor 74 is presented in FIG. 4. In conventional operation, a scroll compressor employs two identical, concentric scrolls 80, 82, one inserted within the other. The first scroll 80 remains stationary as the other scroll 82 orbits around it. This movement draws fluid (i.e., liquid, gas or vapor) into the compression chamber and moves it through successively smaller "pockets" formed by the rotation of the scroll, until it reaches maximum pressure at the center of the chamber. At that point the fluid is released through a discharge port in the fixed scroll. In the present invention, when the scroll compressor 74 is operated in reverse, the function causes the fluid to expand thus becoming an expander 56.

[0035] Referring now to FIG. 5, a single screw compressor 76 has a rotor 84. As the rotor 84 rotates, fluid (i.e., liquid, gas or vapor) is forced through the grooves. The fluid expands through the compressor to expand, thus becoming an expander 56.

[0036] Referring now to FIG. 6, a double screw compressor 78 is illustrated. The male rotor 86 and the female rotor 88 rotate counter to each other. As the lobes of each rotor travel past each inlet port, the fluid (i.e., liquid, gas or vapor) is trapped between consecutive lobes and the cylindrical casing. The fluid moves axially (forward) throughout the case towards the discharge port. The fluid expands through the double screw compressor 78 to expand, thus becoming an expander 56.

[0037] The waste heat recovery generator system 10 is self-contained and fully scalable for use in residential and commercial applications. The waste heat recovery generator system 10 can be coupled to a cogenerator including an internal combustion engine and waste heat recovery unit, such that electrical power can be generated in the cogenerator as well as a portion of the thermal energy captured in the hot/jacket water subsystem and from the engine exhaust. The engine exhaust can then be used as the waste heat source for the waste heat recovery generator system 10 to produce further electrical power. The waste heat recovery generator system 10 of the present invention can convert low temperature waste heat (i.e., waste heat at temperatures as low as about 140°F to about 300°F) into usable mechanical energy for conversion to electricity. Ideally, the waste heat recovery generator system can be scaled to produce from about 3 kilowatts to about 1.5 megawatts of power.

[0038] While the invention has been described with reference to an exemplary embodiment, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention.

[0039] What is claimed is:

CLAIMS

1. A low grade waste heat recovery generator comprising:
an expander generator set having a compressor rotatably coupled to a generator, said compressor rotates in a reverse direction to operate as an expander;

a condenser fluidly coupled to said expander generator set;

a refrigerant pump fluidly coupled to said condenser;

an evaporator fluidly coupled to said refrigerant pump and said expander generator set;
and

a working fluid configured to flow from said evaporator to said expander generator set to said condenser and to said refrigerant pump in a closed loop Organic Rankin Cycle, wherein said working fluid is heated to a temperature of about 140°F to about 300°F.

2. The low grade waste heat recovery generator of Claim 1, wherein said compressor is selected from the group consisting of a single screw compressor, a scroll compressor, and a double screw compressor.

3. The low grade waste heat recovery generator of Claim 1, wherein said working fluid changes state in said evaporator to at least one of liquid to gas and liquid to vapor; and wherein said working fluid changes state in said condenser to at least one of gas to liquid and vapor to liquid.

4. The low grade waste heat recovery generator of Claim 1, wherein said working fluid expands through said expander.

5. The low grade waste heat recovery generator of Claim 1, further comprising:
at least one sensor coupled to said refrigerant pump, said at least one sensor configured to detect vapor wetness; and

at least one microprocessor coupled to said refrigerant pump, said at least one microprocessor configured to control operation of said refrigerant pump.

6. The low grade waste heat recovery generator of Claim 1, further comprising:
a working fluid collector coupled between said condenser and said refrigerant pump.

7. The low grade waste heat recovery generator of Claim 1, wherein said expander rotates said generator to generate electricity.
8. The low grade waste heat recovery generator of Claim 1, further comprising:
a forced convection unit fluidly coupled to said condenser configured to provide forced convective cooling of said condenser.
9. The low grade waste heat recovery generator of Claim 1, further comprising:
a preheater fluidly coupled to said evaporator and said refrigerant pump.
10. The low grade waste heat recovery generator of Claim 1, wherein said evaporator is thermally coupled to a waste heat source and configured to transfer thermal energy from said waste heat source to said working fluid.
11. The low grade waste heat recovery generator of Claim 10, wherein said waste heat source is selected from the group consisting of internal combustion engine, gas turbines, gas flares in landfills, industrial manufacturing processes, incinerators, boilers, geothermal wells and bio-gas.
12. The low grade waste heat recovery generator of Claim 1, wherein said expander operates at about 800 rpms to about 10,000 rpms.
13. The low grade waste heat recovery generator of Claim 1, wherein said expander generator set is disposed in a generator cabinet and is fluidly coupled to a recovery cabinet housing at least said condenser and said evaporator.
14. The low grade waste heat recovery generator of Claim 13, wherein said generator cabinet is mounted on top of said recovery cabinet forming an integrated enclosure.
15. A method of operating a waste heat recovery generator to generate electrical power from low grade waste heat comprising:

transferring thermal energy from a waste heat source to a working fluid in an evaporator, said working fluid is heated to a temperature of about 140°F to about 300°F;

expanding said working fluid through an expander generator set fluidly coupled to said evaporator, said expander generator set having a compressor rotatably coupled to a generator, said compressor rotates in a reverse direction to operate as an expander;

rotating said expander to generate the electrical power in said generator;

condensing said working fluid in a condenser fluidly coupled to said expander generator set; and

flowing said working fluid to a refrigerant pump fluidly coupled to said condenser; and

pumping said working fluid to said evaporator fluidly coupled to said refrigerant pump in a closed loop Organic Rankin Cycle.

16. The method of Claim 15, wherein said compressor is selected from the group consisting of a single screw compressor, a scroll compressor, and a double screw compressor.

17. The method of Claim 15, further comprising:

coupling at least one microprocessor to said refrigerant pump, said at least one microprocessor configured to control operation of said refrigerant pump.

18. The method of Claim 17, wherein said refrigerant pump comprises at least one sensor configured to detect vapor wetness.

19. The method of Claim 15, further comprising:

cooling said condenser with a forced convection unit.

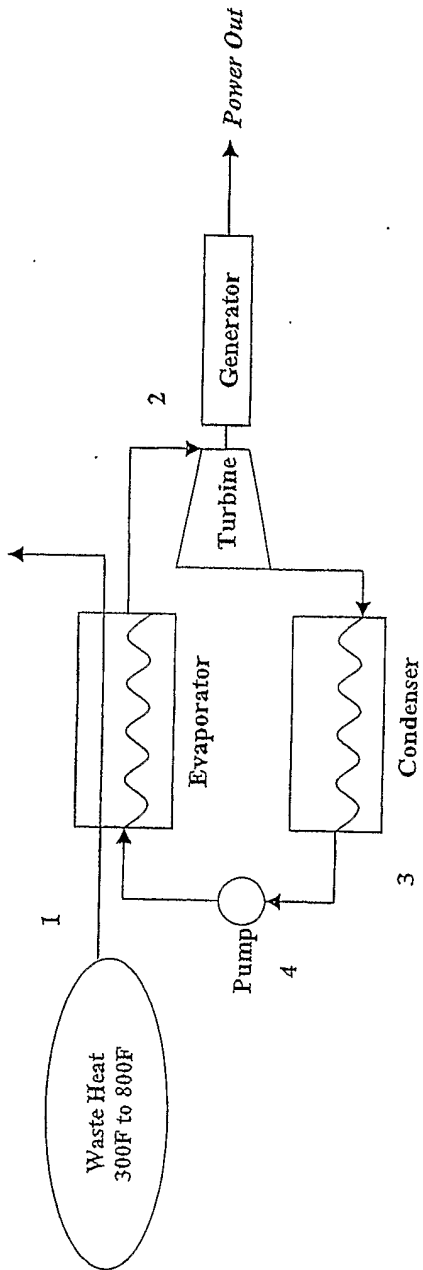


FIG. 1

prior art

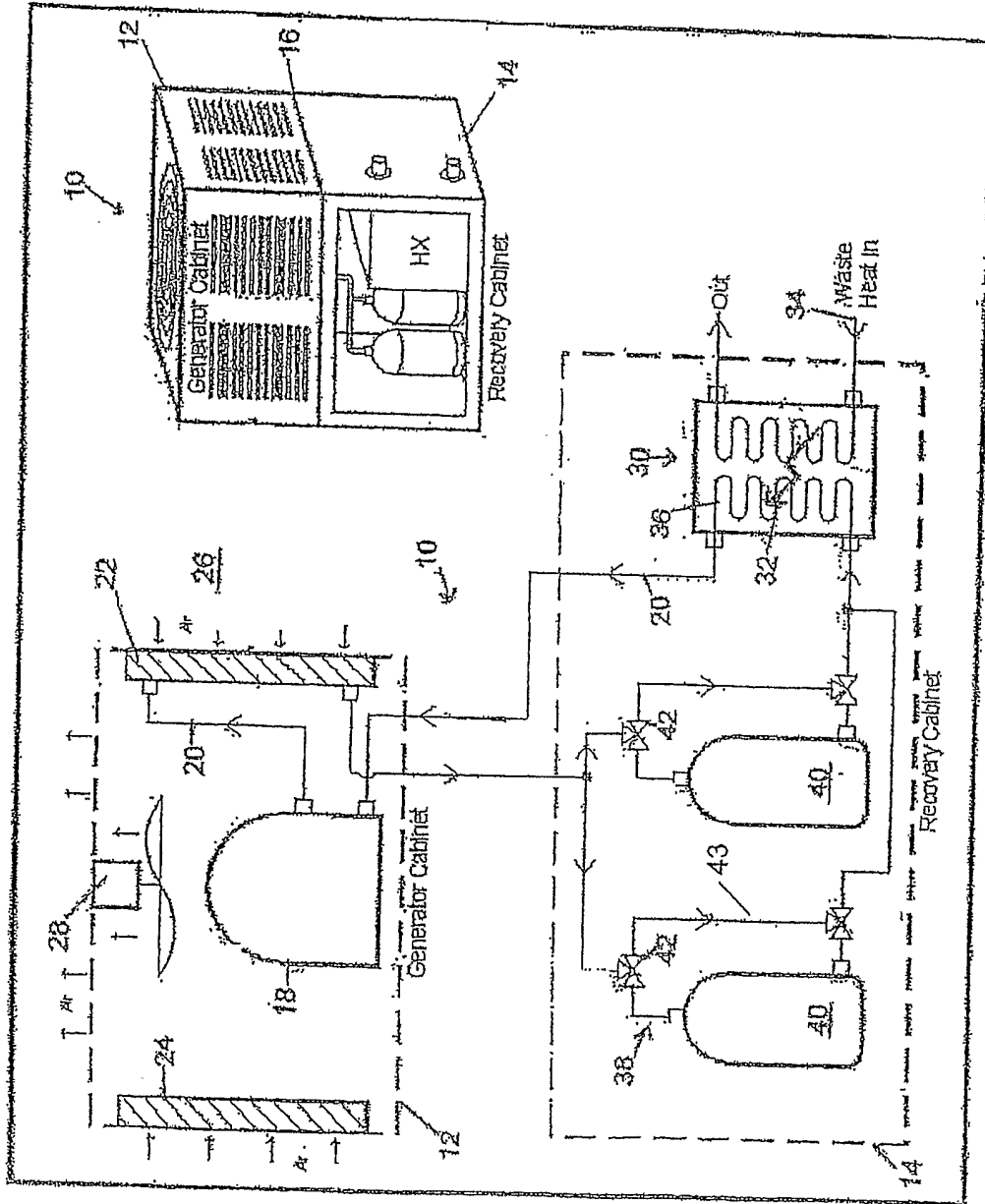


FIG. 2

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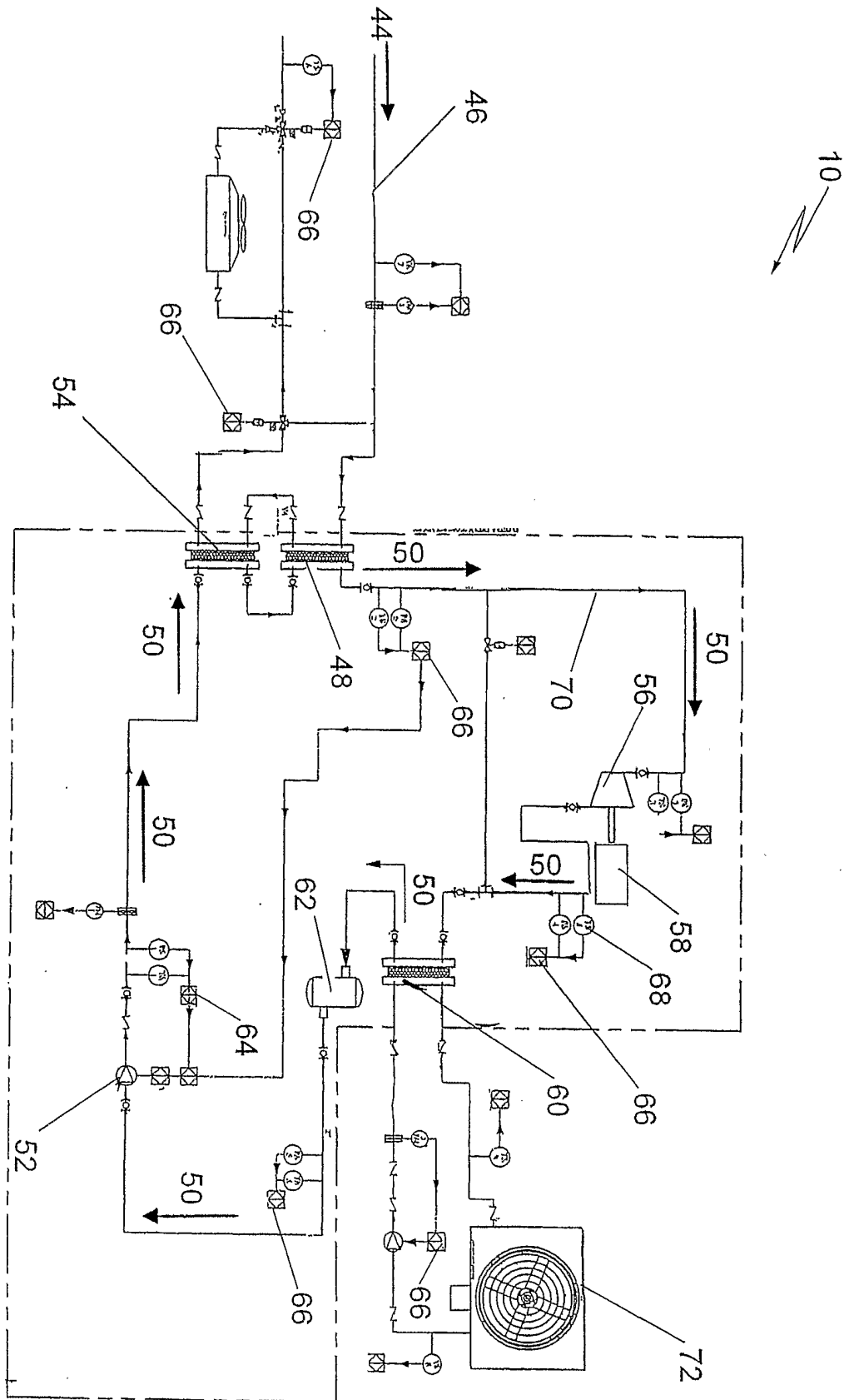


FIG. 3

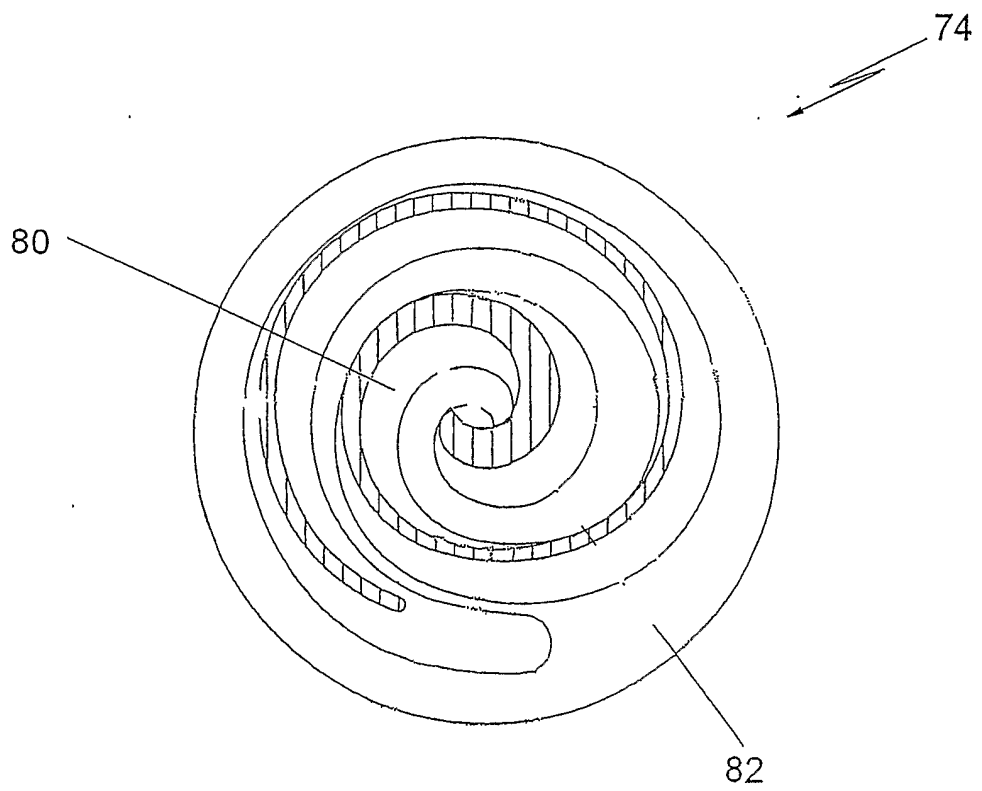


FIG. 4

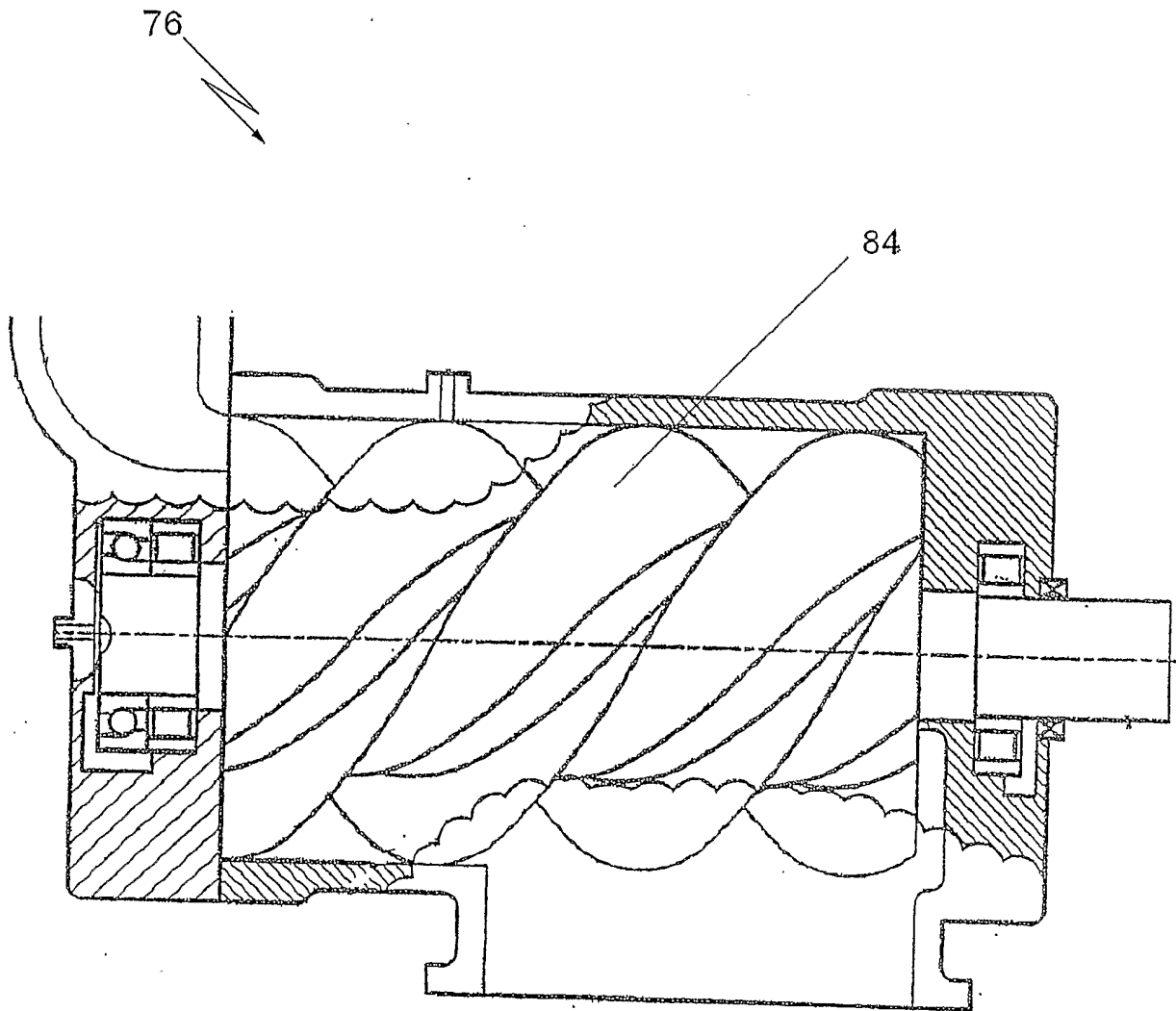


FIG. 5

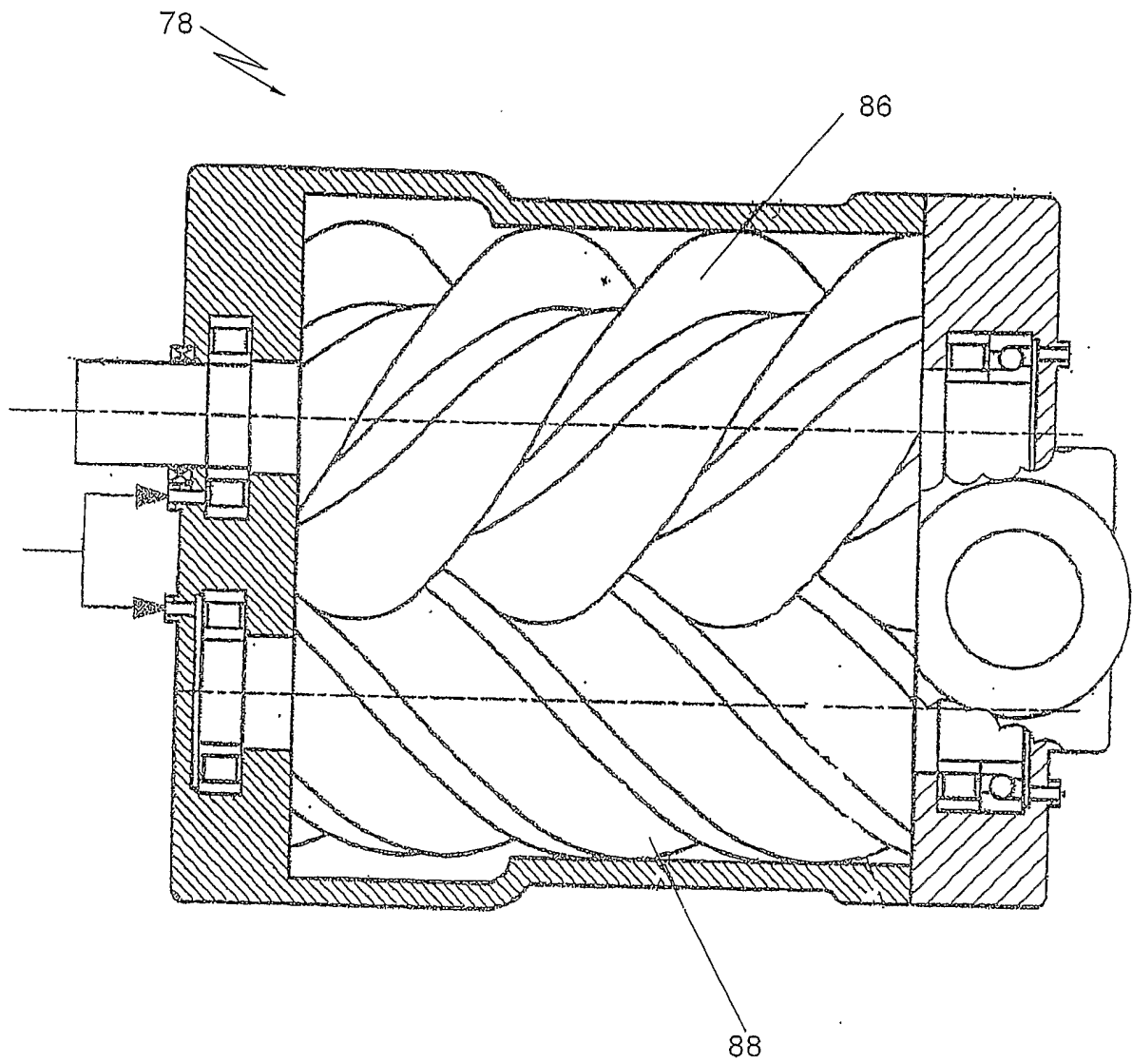


FIG. 6