

Title: A Combined Cooling and Power System and Method

Field of Invention

This invention relates a system and method to produce power and cooling. In particular, by combining the cooling and power system to harness low-grade heat in an effective way.

Background

The rapid increase in global population, urbanization and economic development has seen a significant increase in the demand for energy. By 2050, the global electricity demand is expected to increase 57%. Also, global demand for air-conditioning is expected to triple by 2050. Building energy use (mainly heating and cooling) currently accounts for over 40 % of the total primary energy consumption in the U.S. and the E.U. Presently, most of the electricity is generated by using fossil fuels. The exploitation of fossil resources and their environmental impact demand a transition towards sustainable energy systems.

Summary of Invention

In a first aspect, the invention provides a heat source in heat transfer communication with a first vapour generator. A gas expansion device for receiving an inflow of vapour from the first vapour generator. An ejector for receiving exhaust from the gas expansion device, said ejector arranged to vent gas to a condenser and evaporator in series, said evaporator arranged to vent cooled fluid to the ejector. The ejector is further arranged for receiving inflow of vapour.

Low-grade heat is abundantly available in the form of industrial waste heat. It is estimated that about 20-50% of industrial energy input is released to the atmosphere

through stacks, vents and flares as waste heat. The waste heat recovery market size is estimated to reach US\$ 70.5 billion globally by 2022. In addition, low-temperature heat in the range from 60-100°C is available from renewable sources such as solar and geothermal heat. Therefore, low-grade heat represents an energy potential and its recovery can lead to increasing energy efficiency and the share of renewable energy in the global energy mix.

Combined cooling and power (CCP) systems have been attracting attention in recent years because of their higher energy efficiency and economic benefits and lesser Green House Gas (GHG) emissions. Low-temperature heat driven CCP system are desirable because they may convert waste heat or renewable heat (from solar or geothermal sources) into useful cooling and power in a sustainable way.

Advantageously, this system may be particularly useful for locations having higher ambient temperatures where, under normal conditions, there is less pressure difference available for expander to produce power. By using ejector, the available pressure difference across expanders can be increased by this system while utilizing the same ejector for producing cooling as well.

In a second aspect, the system may include two pressure levels, where two pumps and two vapour are used. The two different pressures are maintained by the two pumps. The heat source is configured in heat communication with a second vapour generator and the ejector is arranged to receive vapour from the second vapour generator.

Advantageously, due to two pressure levels, two pumps and two vapour generators are used in this system. This system is more suitable when the two sources of heat are available. The system can extract more heat from a single source of heat because of lower pressure vapour generation.

Brief Description of Drawings

The invention will be described in detail with reference to the accompanying drawings, in which:

Fig. 1 shows a perspective view of the power system according to one embodiment of the invention;

Fig. 2 shows a perspective view of a power system according to one embodiment of the invention;

Fig. 3 shows an exploded view of an ejector according to one embodiment of the invention.

Detailed Description of Embodiments of the Invention

In the following description, numerous specific details are set forth in order to provide a thorough understanding of various illustrative embodiments of the invention. It will be understood, however, to the skilled person that embodiments of the invention may be practiced without some or all of these specific details. It is understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to limit the scope of the invention. In the drawings, like reference numerals refer to same or similar functionalities or features throughout the several views.

Referring to Fig. 1, a system 100 for generating power from low-grade heat according to one embodiment of the present invention. The system 100 includes a vapour generator 102, a pump 104, a gas expansion device 106, an ejector 108, a condenser 110, an evaporator 112 and a heat source 114. The ejector 108 may include more than one inlet for receiving for receiving fluid. A heat source 114 is in heat transfer communication with a first vapour generator 102. The outlet of the first vapour generator 102 is connected to the inlet of the gas expansion device 106 and the inlet of the ejector 108. The first vapour generator 102 is capable of producing a first vapour.

The gas expansion device 106 is arranged for receiving an inflow of vapour from the first vapour generator 102. The first vapour leaves the gas expansion device 106 as exhaust. The outlet of the gas expansion device 106 is connected to the inlet of the ejector 108, where the ejector is arranged for receiving exhaust from the gas expansion device 106. The fluid from the outlet of the gas expansion device 106, outlet of the first vapour generator 102, and outlet of the evaporator 112 forms a vent gas. The outlet of the ejector 108 is connected to an inlet of condenser 110, where the vent gas leaves the ejector and enter the inlet of the condenser 110. The outlet of the condenser 110 is connected to an inlet of an evaporator 112 and an inlet of a pump 104 arranged in parallel. The cooled fluid is vent from the outlet of the condenser 110 to the inlet of the evaporator 112 and the inlet of the pump 104. The outlet of the evaporator 112 is connected to the inlet of the ejector 108. The evaporator 112 is arranged to vent the cooled fluid to the inlet of the ejector 108. The inlet of the pump 104 is connected to the outlet of the first vapour generator 102. The cooled fluid is then pumped from the outlet of the pump 104 into the inlet of the first vapour generator 102.

Referring to Fig. 2, a system 200 employs a first vapour generator 202, a second vapour generator 206, a first pump 204, a second pump 206, a gas expansion device 208, an ejector 108, a condenser 214, an evaporator 212, an expansion valve 218, a first heat source 216 and a second heat source 220. The ejector 108 may include more than one inlet for receiving fluid. The first vapour generator 202 may be a high temperature generator and the second vapour generator 206 may be a low temperature generator, the generators operate at two different pressures and the pressure are maintain by a first pump 204 and a second pump 206. A first heat source 216 is connected to an inlet of the first vapour generator 202. A second heat source 220 is connected to an inlet of the second vapour generator 206. The first heat source 216 may be of a higher temperature than the second heat source 220. The outlet of the first vapour generator 202 is connected to the inlet of the gas expansion device 208. The gas expansion device 208 is arranged for receiving inflow of vapour from the first vapour generator 202. The outlet of the gas expansion device 208 is connected to an inlet of the ejector 108. The gas

expansion device 208 is arranged to receive an inflow of vapour from the gas expansion device 208. The outlet of the second vapour generator 208 is connected to the inlet of the ejector 108. A vapour exits the outlet of the second vapour generator 208 and enters the inlet of the ejector 108. The vapour exiting the outlet of the second vapour generator 206 may be a saturated vapour. The vapours exiting for both the gas expansion device 208 and the second vapour generator 206 is entrained by the ejector 108, thus forming a working fluid. The outlet of the ejector 108 is connected to an inlet of the condenser 214. The working fluid exits the outlet of the ejector 108 and enters the inlet of the condenser 214 forming a condensed fluid.

In one embodiment, a first heat source 216 in heat transfer communication with a first vapour generator 202. A gas expansion device 208 for receiving an inflow of vapour from the vapour generator 202. An ejector 108 for receiving exhaust from the gas expansion device 208, said ejector 108 arranged to vent gas to a condenser 214 and evaporator 212 in series, said evaporator 212 arranged to vent cooled fluid to the ejector 108, where the system further includes a second heat source 220 in heat transfer communication with a second vapour generator 206, said ejector 108 further arranged to receive vapour from the second vapour generator 206.

Alternatively, the first vapour generator 202 may be arranged to receive fluid from the condenser 214.

Alternatively, the second vapour generator 206 may be arranged to receive fluid from the condenser 214.

Alternatively, the first heat source 216 may include an inflow of a heated heat transfer fluid, the first vapour generator 202 may include a heat exchanger providing heat transfer communication between inflow of the heated heat transfer fluid and fluid received from the condenser 214.

Alternatively, the second heat source 220 may include an inflow of the heat transfer fluid from the first vapour generator 202, said second vapour generator 206 may include a heat exchanger providing heat transfer communication between the inflow of heat transfer fluid and fluid received from the condenser 214.

An outlet of the condenser 214 is connected to an inlet of the expansion valve 218, an inlet of the second pump 207 and an inlet of the first pump 204. The condensed fluid is divided in three streams. The first stream exits the outlet of the condenser 214 and enters the inlet of expansion valve 218. The second stream exits the outlet of the condenser 214 and enters the inlet of the second pump 207. The third stream exits the outlet of the condenser 214 and enters the inlet of the first pump 204. An outlet of the expansion valve 218 is connected to an inlet of the evaporator 212. The condensed fluid undergoes isenthalpic expansion in the expansion valve 218 and forms a wet vapour. The wet vapour exits the outlet of the expansion valve 218 and enters the inlet of the evaporator 212. An outlet of the evaporator 212 is connected to an inlet of the ejector 108. A vapour exits the outlet of the evaporator 212 and enters the inlet of the ejector 108. The second steam and third steam exiting the condenser may be a liquid. An outlet of the second pump 207 is connected to the inlet of the second vapour generator 206.

Alternatively, the first heat source 216 may include an inflow of a heated heat transfer fluid, the first vapour generator 202 including a heat exchanger providing heat transfer communication between inflow of the heated heat transfer fluid and fluid received from the condenser 214.

Alternatively, the second heat source 220 may include an inflow of the heat transfer fluid from the first vapour generator 202, said second vapour generator 206 including a heat exchanger providing heat transfer communication between the inflow of heat transfer fluid and fluid received from the condenser 214.

The method for generating power in a power system comprising the steps as follows:

Transferring heat from a first heat source 216 to a first vapour generator 202, producing an inflow of vapour from the first vapour generator 202 to a gas expansion device 208. Subsequently, expanding the vapour through the gas expansion device 208, producing an exhaust from the gas expansion device 208 and transferring the exhaust to an ejector 108. Cooling the gas through a condenser 214 and so forming a cooled fluid, delivering the cooled fluid from an evaporator 212 to the ejector 108. Transferring heat from a second heat source 220 to a second vapour generator 206, the second vapour generator 206 providing a second vapour inflow to the ejector 108.

Alternatively, the method may include the step of receiving fluid from the condenser 214 to the first vapour generator 202.

Alternatively, the method may include the step of receiving fluid from the condenser 214 to the second vapour generator 206.

Alternatively, the method may include the steps of transferring heat from fluid received from the condenser 214 and a heated heat transfer fluid to said first vapour generator 202, wherein the first heat source 216 may include an inflow of the heated heat transfer fluid.

Alternatively, the method may include the steps of transferring heat from fluid received from the condenser 214 and the heat transfer fluid to said second vapour generator 206, the second heat source 220 includes an inflow of the heat transfer fluid from the first vapour generator 202.

Referring to Fig. 3, the ejector 108 includes a nozzle 302, a suction chamber 304, a mixing chamber 306 and a diffuser 308. The nozzle 302 may include at least two

intake, the first intake for receiving a primary fluid 310, the second intake for receiving a secondary fluid 312. The nozzle 302 is arranged to receive a first fluid inflow. The primary fluid 310 may include exhaust from the expander 106, 208 and vapour from the first vapour generator 102, 202. The secondary fluid 312 may include a cooled fluid from the condenser 112, 212. The nozzle 302 may be a convergent-divergent nozzle or a venturi nozzle. The primary fluid 310 may be high-pressure fluid and the secondary flow 312 may be low-pressure fluid. The primary fluid accelerates at the cost of pressure drop and induces the low-pressure secondary fluid. The suction chamber 304 arranged to receive a cooled fluid. The nozzle 302 and the suction chamber 304 arranged to combine the cooled fluid and fluid inflow in a mixing chamber 306. The mixing chamber 306 may be conical in shape and diverts at one end towards the diffuser. The mixing chamber 306 is arranged to impinge the combined fluid such that the impinged fluid undergoes a compression shock thus forming the vent gas to a diffuser 308. The compression shock in the mixing chamber 306 which results in abrupt increase in pressure and a decrease in velocity and the flow becomes subsonic. The diffuser 308 is arranged to increase the pressure of the vent gas. The area ratio of an ejector is one of the main geometric parameters and is defined as the ratio of areas of diffuser inlet and primary nozzle throat and is given by $(D_m/D_t)^2$, where D_m is the diameter of the diffuser inlet and D_t is the diameter of the throat of the nozzle. Ejector performance is often measured by its entrainment ratio which is the ratio of the secondary and primary mass flow rates. An ejector with higher entrainment ratio requires a smaller mass flow rate of the motive fluid and thus a lower heat input which means higher system performance. Both operating conditions and geometry of ejector affect the entrainment ratio. For a given ejector, the entrainment ratio decreases with increasing generator pressure and with decreasing evaporator pressure. Fixed dimension ejectors operate only within a small operating temperature and pressure range. To cater for varying operating conditions, multi-ejector systems can be developed along with suitable control systems, also, ejectors with adjustable dimensions could be developed.

Alternatively, the nozzle 302 may be further arranged to receive a second fluid inflow and directing said second fluid flow to the mixing chamber 306.

The system and method extracts heat in two stages by utilizing preferably two vapour generators operating at two different pressures, such that more heat can be extracted from the heating stream,. The system may give a higher output as compared to a single stage heat extraction in other system for the same heat temperature and flow rate.

Claims

1. A power system comprising:
 - a first heat source in heat transfer communication with a first vapour generator
 - a gas expansion device for receiving an inflow of vapour from the first vapour generator;
 - an ejector for receiving exhaust from the gas expansion device, said ejector arranged to vent gas to a condenser, and an evaporator in series, said evaporator arranged to vent cooled fluid to the ejector;
 - wherein the system further includes a second heat source in heat transfer communication with a second vapour generator, said ejector further arranged to receive vapour from the second vapour generator.
2. The power system according to claim 1, wherein the first vapour generator is arranged to receive fluid from the condenser.
3. The power system according to claim 1 or 2, wherein the second vapour generator is arranged to receive fluid from the condenser.

4. The power system according to any one of claims 1 to 3, wherein the first heat source includes an inflow of a heated heat transfer fluid, the first vapour generator including a heat exchanger providing heat transfer communication between inflow of the heated heat transfer fluid and fluid received from the condenser.
5. The power system according to claim 4, wherein the second heat source includes an inflow of the heat transfer fluid from the first vapour generator, said second vapour generator including a heat exchanger providing heat transfer communication between the inflow of heat transfer fluid and fluid received from the condenser.
6. A method of generating power for a power system, comprising the steps of:
 - transferring heat from a first heat source to a first vapour generator;
 - producing an inflow of vapour from the first vapour generator to a gas expansion device;
 - expanding the vapour through the gas expansion device;
 - producing an exhaust from the gas expansion device;
 - transferring the exhaust to an ejector;
 - cooling the gas through a condenser and so forming a cooled fluid;

delivering the cooled fluid from an evaporator to the ejector;

transferring heat from a second heat source to a second vapour generator;

the second vapour generator providing a second vapour inflow to the ejector.

7. The method according to claim 6, further including the step of receiving fluid from the condenser to the first vapour generator.
8. The method according to claim 6 or 7, further including the step of receiving fluid from the condenser to the second vapour generator .
9. The method according to any one of claims 6 to 8, further including the steps of transferring heat from fluid received from the condenser and a heated heat transfer fluid to said first vapour generator;

wherein the first heat source includes an inflow of the heated heat transfer. .
10. The method according to claims 6 to 9, further including the steps of transferring heat from fluid received from the condenser and the heat transfer fluid to said second vapour generator;

wherein the second heat source includes an inflow of the heat transfer fluid from the first vapour generator.