ORGANIC RANKINE CYCLE AUGMENTED POWER SUPPLY SYSTEM FOR MOBILE REFRIGERATION UNITS

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ABSTRACT

A mobile refrigeration unit includes a refrigeration system having a plurality of electric motor driven components and an on-board power supply system for generating electric current and supplying the electric current to the plurality of electric motor driven components. The power supply system includes a first generator for generating a first portion of electric power, a second generator for generating a first portion of electric power, a fuel fired engine driving the first generator, and an organic Rankine cycle system driving the second generator. An engine exhaust line connects the fuel-fired engine in exhaust gas flow communication with the organic Rankine system. The unit may also include a storage battery and a power management system.
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BACKGROUND OF THE INVENTION

[0001] This invention relates generally to mobile refrigeration units and, more particularly, to a mobile refrigeration unit having an on-board power supply system for generating electric current for driving a plurality of components of a refrigeration system of the mobile refrigeration unit.

[0002] Refrigerated trucks and trailers are commonly used to transport perishable goods, such as, for example, produce, meat, poultry, fish, dairy products, cut flowers, and other fresh or frozen perishable products. A transport refrigeration unit is mounted to the truck or to the trailer operatively associated with a cargo space defined within the truck or trailer for maintaining a controlled temperature environment within the cargo space.

[0003] On commercially available transport refrigeration units used in connection with refrigerated trucks and refrigerated trailers, the compressor, and typically other components of the refrigeration system, for example fans, are powered by a prime mover, typically a diesel engine, carried on and considered part of the transport refrigeration unit. In all electric transport refrigeration units, such as, for example, the all electric transport refrigeration unit disclosed in U.S. Pat. No. 6,223,546, assigned to Carrier Corporation, an on-board diesel engine drives an on-board AC synchronous generator that generates AC current used to power an electric compressor motor for driving the refrigerant compressor of the transport refrigeration unit and also powering electric AC fan motors for driving the condenser/gas cooler and evaporator fans.

[0004] In transport refrigeration applications, the diesel engine is sized sufficiently to drive the electric generator to generate all the electric power required to power the refrigeration system when operating at maximum cooling capacity, such as during pull down of the temperature within the cargo space of the truck or trailer. However, when the refrigeration system is operating at a lower steady state capacity, such as during operation for maintaining the temperature within the cargo space within a narrow range of a set point control temperature, the diesel engine is operated at a reduced throttle setting to reduce fuel consumption. However, when operating at a lower throttle setting, the efficiency of the diesel engine is also reduced.

SUMMARY OF THE INVENTION

[0005] In an aspect, a mobile refrigeration unit is provided that includes an on-board power supply system wherein waste heat from a fuel-fired engine is recovered and used in generating additional electric power to augment the electric power generated by the diesel engine.

[0006] The mobile refrigeration unit includes a refrigeration system having a plurality of electric motor driven components and an on-board power supply system for generating electric current and supplying the electric current to the plurality of electric motor driven components. The power supply system includes: a first generator for generating a first portion of electric power for powering the plurality of electric motor driven components; a second generator for generating a first portion of electric power for powering the plurality of electric motor driven components; a fuel fired engine driving the first generator; and an organic Rankine cycle system driving the second generator. An engine exhaust line connects the fuel-fired engine in exhaust gas flow communication with the organic Rankine system whereby a portion of the waste heat in the engine exhaust gases may be recovered and used in the organic Rankine cycle system.

[0007] The mobile refrigeration unit may further include a storage battery and a power management system including a power-switching module in electric connection with the first generator, the second generator, and the storage battery. The power management system is configured to selectively direct electric current received from the first generator and the second generator to power the electric components of the refrigeration system as needed. The power management system may be configured to direct any excess electric current generated to the storage battery. The power management system may be configured to draw electric current from the storage battery as needed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] For a further understanding of the disclosure, reference will be made to the following detailed description which is to be read in connection with the accompanying drawing, wherein:

[0009] FIG. 1 is a side elevation view of a refrigerated trailer equipped with a transport refrigeration unit;

[0010] FIG. 2 is a schematic diagram illustrating an embodiment of a transport refrigeration unit having a power supply system including an organic Rankine system augmenting a diesel engine; and

[0011] FIG. 3 is a schematic diagram illustrating an embodiment of the power supply system disclosed herein.

DETAILED DESCRIPTION OF THE DISCLOSURE

[0012] Referring initially to FIG. 1, there is depicted a refrigerated transport vehicle 12 for transporting perishable goods in a temperature controlled environment. In the depicted embodiment, the refrigerated transport vehicle 12 is a refrigerated tractor-trailer having a tractor 14 pulling a trailer 16 defining a cargo box 18. A mobile refrigeration unit 20 is mounted to the trailer 16, for example to the front wall of the trailer 16, for establishing and maintaining a temperature-controlled environment within the cargo box 18. In this application, the mobile refrigeration unit 20 is commonly referred to as a transport refrigeration unit (TRU), which terminology will be used herein.

[0013] The transport refrigeration unit 20 includes an on-board power supply system 22 and a refrigeration system 24. As illustrated schematically in FIG. 2, the refrigeration system comprises a refrigerant vapor compression system having a compression device 26, a refrigerant heat rejection heat exchanger 28, an expansion device 25, and a refrigerant heat absorption heat exchanger 30 disposed in serial refrigerant flow relationship in a refrigerant circuit and arranged to carry out a refrigeration cycle. The compression device 26, the refrigerant heat rejection heat exchanger 28 and the power supply system 22 are disposed external of the trailer 12, while the refrigerant heat absorption heat exchanger 30, which functions as an evaporator, is disposed in operative association with the compressor, using the cargo box 18. 18.

[0014] The compression device 26 is driven by an electric motor 32 to compress refrigerant from a suction pressure to a
discharge pressure and circulate the refrigerant through the refrigerant circuit. The compression device 26 may be any electric motor driven compressor, hermetic or semi-hermetic, such as, for example, but not limited to a reciprocating compressor, a scroll compressor, or other refrigeration compressor.

[0015] The hot, high pressure refrigerant vapor discharged from the compression device 26 passes through the refrigerant heat rejection heat exchanger 28 in heat exchange relationship with a cooling medium, typically ambient air. Depending upon the type of refrigerant with which the refrigerant circuit is charged, the refrigerant heat rejection heat exchanger 28 functions either as a refrigerant gas cooler or a refrigerant gas condenser. In either case, an air moving device 34 passes ambient air from the environment external of the refrigeration unit through the refrigerant heat rejection heat exchanger 28 in heat exchange relationship with the refrigerant passing through the refrigerant heat rejection heat exchanger 28. The gas cooler/condenser air moving device 34 is driven by an electric motor 36. In an embodiment, the gas cooler/condenser air moving device 34 may comprise an electric motor driven fan, such as an axial fan or a centrifugal fan.

[0016] The refrigerant heat absorption heat exchanger 30 functions as an evaporator wherein refrigerant having traversed the expansion device 25, which may be an electronic expansion valve, a thermostatic expansion valve, a capillary tube or other expansion device, is passed with air drawn from the temperature controlled environment with the cargo box 18, whereby the refrigerant is evaporated and typically superheated and the air cooled. An air moving device 38 is provided for drawing air from the cargo box 18, i.e., the temperature controlled space, passing the air through the refrigerant heat rejection heat exchanger 30, and circulating the cooled air back to the cargo box 18. The evaporator air moving device 38 is driven by an electric motor 40. In an embodiment, the evaporator air moving device 38 may comprise an electric motor driven fan, such as an axial fan or a centrifugal fan.

[0017] The power supply system 22 generates electric current and supplies electric current as needed to power a plurality of electric motor driven components of the refrigerant vapor compression system, including the aforementioned compression device drive motor 32, the gas cooler/condenser electric drive motor 36, and the evaporator electric drive motor 40. The power supply system 22 may also supply electric current to power a refrigeration system controller (not shown), various control devices such as solenoid valves and other electronic valves and devices, lighting and electric current consuming devices. The power supply system may be configured to provide alternating current (AC) power, direct current (DC) power, or both AC and DC power.

[0018] Referring to FIGS. 2 and 3, the power supply system 22 includes a first generator 42 for generating a first portion of electric power for powering the plurality of electric motor driven components, a second generator 44 for generating a first portion of electric power for powering the plurality of electric motor driven components, a fuel-fired engine 46 driving the first generator 42, and an organic Rankine cycle (ORC) system 48 driving the second generator 44. In an embodiment, the fuel-fired engine 46 comprises a Diesel fueled piston engine. However, it is to be understood that the fuel-fired engine 46 may comprise virtually any fueled-fired engine alternative that produces exhaust gases. For example, but not limitation, instead of a Diesel-fueled piston engine, the fuel-fired engine 46 may comprise, a gas turbine engine, a natural gas or propane fueled piston engine, or turbine engines combusting various fuels.

[0019] The power supply system 22 further includes a power management system 72 that includes a power switching module 74 and a power bus 76 which is in electrical communication with and receives the current generated by each of the first and second generators 41 and 42. The power bus 76 is in electrical communication with each of the refrigeration system loads, including but not limited to the compressor motor 32, the condenser/gas cooler fan 36 and the evaporator fan 40. The power bus 76 is also in electrical communication with the power switching module 74 whereby electric may be selectively supplied to the power bus 76. In an embodiment, each of the first and second generators 42 and 44 may comprise alternating current (AC) generators. By way of example, but not limitation, in an embodiment each of the first and second generators 42 and 44 may comprise engine driven synchronous AC generators of the type disclosed in U.S. Pat. No. 6,321,550, assigned to Carrier Corporation. However, it is to be understood that the power management system 72 may be configured to receive either or both AC and DC current and distribute either or both AC and DC current.

[0020] The ORC system 48 may comprise a conventional ORC system having a working fluid pump 50, a working fluid evaporator 52, an expander 54, and a condenser 56 disposed in series refrigeration flow relationship in a closed loop working fluid circuit. The ORC system 48 may also include a regenerative heat exchanger 60 having a first pass 62 and a second pass 64 disposed in heat exchange relationship, the first pass 62 disposed in the working fluid circuit between the pump 50 and the working fluid inlet to the evaporator 52 and the second pass 64 disposed in the working fluid circuit 58 between the working fluid outlet of the evaporator 52 and the working fluid inlet to the condenser 56.

[0021] An air moving device 58 may be provided in operative association with condenser 56 for passing ambient air through the condenser 56 in heat exchange with the working fluid passing through the condenser 56 to cool the working fluid. In an embodiment, as depicted in FIG. 2, the air moving device 58 comprises a fan driven by an electric motor 55 powered by electric current generated by the power supply system 22. Alternatively, the air moving device 58 could be belt driven off the fuel-fired engine 46. In a further embodiment, not shown, the condenser 56 of the ORC system 48 could be disposed in association with the condenser/gas cooler 28 of the refrigeration system 24 whereby the condenser/gas cooler air moving device, e.g., electric motor driven fan 34, passes a flow of ambient air as the cooling medium through both the ORC condenser 56 and the refrigeration system condenser 28.

[0022] When the fuel-fired engine 46 is operating, the combustion of the fuel produces exhaust gases that are vented to the atmosphere. In the refrigeration unit 20 and method disclosed herein, a portion of the waste heat content of the hot exhaust gases is recovered and utilized in the ORC system 48. As depicted in FIGS. 2 and 3, the refrigeration unit 20 further includes an engine exhaust line 66 connecting the exhaust system of the fuel fired engine 46 in exhaust gas flow communication with the ORC system 48, whereby a portion of waste heat in the engine exhaust gases may be recovered in the ORC system. For example, as depicted in FIG. 2, the evaporator 52 of the ORC system 48 may include an exhaust gas pass 68 disposed in heat exchange relationship with a working fluid pass 70 whereby the working fluid circulating
through the working fluid circuit 58 as the working fluid pass 70 passes in heat exchange relationship with the hot exhaust gases passing through the exhaust gas pass 68 prior to venting into the atmosphere.

[0023] The engine exhaust gases typically have a temperature in the range of 500°F.-600°F. (260°C.-315°C.) for small Diesel fueled engines to as high as 1200°F. (649°C.) for large Diesel fueled engines. When the fueled-fired engine 46 is operating at maximum rpm, such as during operation of the refrigeration system during pull down of the temperature within the cargo box 18 to a desired set point temperature for the particular perishable goods in transport, a relatively larger volume flow of engine exhaust gases are generated as compared to a relatively smaller volume flow of engine exhaust gases produced when the engine is operating in a low refrigeration output mode, such as during maintenance of the temperature within the cargo box 18 within a narrow band about the set point temperature.

[0024] Therefore, when maximum cooling demand is imposed on the refrigeration system 24, and consequently maximum demand is imposed on the power supply system 22 for electric current to power the plurality of electric motor driven components of the refrigeration system, a high volume flow of hot engine exhaust gases will flow through the exhaust line 66 to pass through the exhaust gas pass 68 of the evaporator 52 of the ORC system 48. Thus, the maximum amount of waste heat is made available to the ORC system 48 precisely when the maximum electric current output from the second generator 44 driven by the ORC system 48 is needed to augment the electric current output from the first generator 42 driven by the fuel-fired engine 46.

[0025] However, when the refrigeration demand is low, such as when the refrigeration system 24 is operating in a temperature maintenance mode, the fuel-fired engine 46 will be operated at a lower throttle to conserve fuel and a lower volume flow of hot engine gases will flow through the exhaust gas pass 68 of the evaporator 52 of the ORC system 48. Consequently, the amount of waste heat supplied to the ORC system 48 and the electric current output generated by the second generator 44 driven by the ORC system 48 will be lower. Additionally, since the fuel-fired engine 46 is operated at a lower throttle, the electric current output produced by the second generator 42 driven by the engine 46 will be reduced. Thus, the combined electric current output of the first generator 42 driven by the fuel fired engine 46 and the second generator 44 driven by the ORC system 48 will be lower precisely when the electric current demand to power the refrigeration system loads will be at or near its lowest imposed current demand when the refrigeration system 24 is in operation.

[0026] Further, when the refrigeration demand is low, such as when the refrigeration system 24 is operating in a temperature maintenance mode, the combined electric current output from the first generator 42 driven by the fuel-fired engine 46 and the second generator 44 driven by the ORC system 48 may exceed the demand for electric current imposed by the refrigeration system 24. In such event, the excess electric current generated may be directed by the power switching module 74 to a power storage device, such as storage battery 78. A power conditioner 80 may be interdispersed in electric communication between the power switching module 74 and the storage battery 78. The power conditioner 80 may include one or more of an AC to DC convertor 82, a DC to AC convertor 84, and a DC to DC conditioner 86.

[0027] For example as illustrated in FIGS. 2 and 3, when excess AC current is being generated by the first and second generators 42 and 44 and delivered to the power management system 72, the power switching module may be configured to direct that excess AC current to the power conditioner 80 wherein the AC current passes through the AC to DC converter 82 and is delivered to the storage battery 78 as DC current and stored for later use. If at any time, supplemental power is required to augment the AC current then being generated by the first and second generators 42 and 44, the power management system 72 may be configured to draw DC current from the storage battery 78 through the power conditioner 80, wherein the DC current is converted to AC current by the DC to AC convertor 84, to the power switching module 74 which directs the AC current to the power bus 76. The power management module 72 may also be configured to draw DC current from the storage battery 78 through the DC to AC conditioner 86, which for example include a voltage step-up transformer and/or a voltage step-down transformer, to the power switching device 74 to be delivered to the power bus 76 for powering refrigeration system DC loads, such as for example, electronic controllers, computers, control valves.

[0029] The refrigeration unit 20 disclosed herein has been described in a transport refrigeration application for establishing and maintaining a temperature controlled environment within a cargo box of a transport refrigeration vehicle. However, it is to be understood that the refrigeration unit 20 disclosed herein may also be used in other mobile refrigeration applications where a refrigeration unit equipped with a self-contained electric power generation capability is desired.

[0030] The terminology used herein is for the purpose of description, not limitation. Specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as basis for teaching one skilled in the art to employ the present invention. Those skilled in the art will also recognize the equivalents that may be substituted for elements described with reference to the exemplary embodiments disclosed herein without departing from the scope of the present invention.

[0031] While the present invention has been particularly shown and described with reference to the exemplary embodiments as illustrated in the drawings, it will be recognized by those skilled in the art that various modifications may be made without departing from the spirit and scope of the invention. Therefore, it is intended that the present disclosure not be limited to the particular embodiment(s) disclosed, but that the disclosure will include all embodiments falling within the scope of the appended claims.

We claim:

1. A mobile refrigeration unit comprising:
a refrigeration system having a plurality of electric motor driven components; and
an on-board power supply system for generating electric current and supplying the electric current to the plurality of electric motor driven components, the power supply system having:

a first generator for generating a first portion of electric power for powering the plurality of electric motor driven components;

a second generator for generating a first portion of electric power for powering the plurality of electric motor driven components;

a fuel fired engine driving the first generator; and

an organic Rankine cycle system driving the second generator.

2. The mobile refrigeration unit as recited in claim 1 further comprising an engine exhaust line connecting the fuel fired engine in exhaust gas flow communication with the organic Rankine system.

3. The mobile refrigeration unit as recited in claim 1 wherein the fuel fired engine comprises a diesel engine.

4. The mobile refrigeration unit as recited in claim 1 further comprising:

a storage battery; and

a power management system including a power switching module in electric connection with the first generator, the second generator, and the storage battery.

5. The mobile refrigeration unit as recited in claim 4 wherein power system management system comprises at least one of an AC power bus and a DC power bus.

6. The mobile refrigeration unit as recited in claim 4 wherein the power management system comprises an AC-to-DC converter in electric communication with the storage battery and the power switching module.

7. The mobile refrigeration unit as recited in claim 4 wherein the power management system comprises a DC-to-AC converter in electric communication with the storage battery and the power switching module.

8. The mobile refrigeration unit as recited in claim 1 wherein the refrigeration system comprises a refrigerant vapor compression system having a refrigerant compressor, a refrigerant heat rejection heat exchanger, and a refrigerant heat absorption heat exchanger disposed in a refrigerant flow circuit in a series refrigerant flow relationship.

9. The mobile refrigeration unit as recited in claim 8 wherein the plurality of electric motor driven components includes the refrigerant compressor, at least one air moving device operatively associated with the refrigerant heat rejection heat exchanger, and at least one air moving device operatively associated with the refrigerant heat rejection heat exchanger.

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