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(54) **FULL FUNCTION VEHICLE HVAC/PTC THERMAL SYSTEM**

(75) Inventors: **Lawrence P. Ziehr**, Clarkston, MI (US); **Gregory A. Major**, Beverly Hills, MI (US); **June S. Bian**, Northville, MI (US)

(73) Assignee: **General Motors Corporation**, Detroit, MI (US)

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See application file for complete search history.

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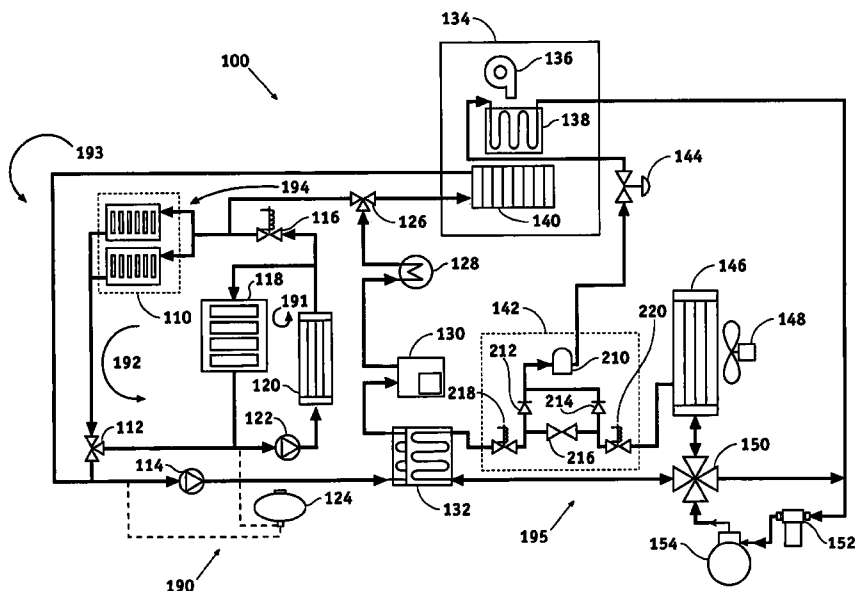
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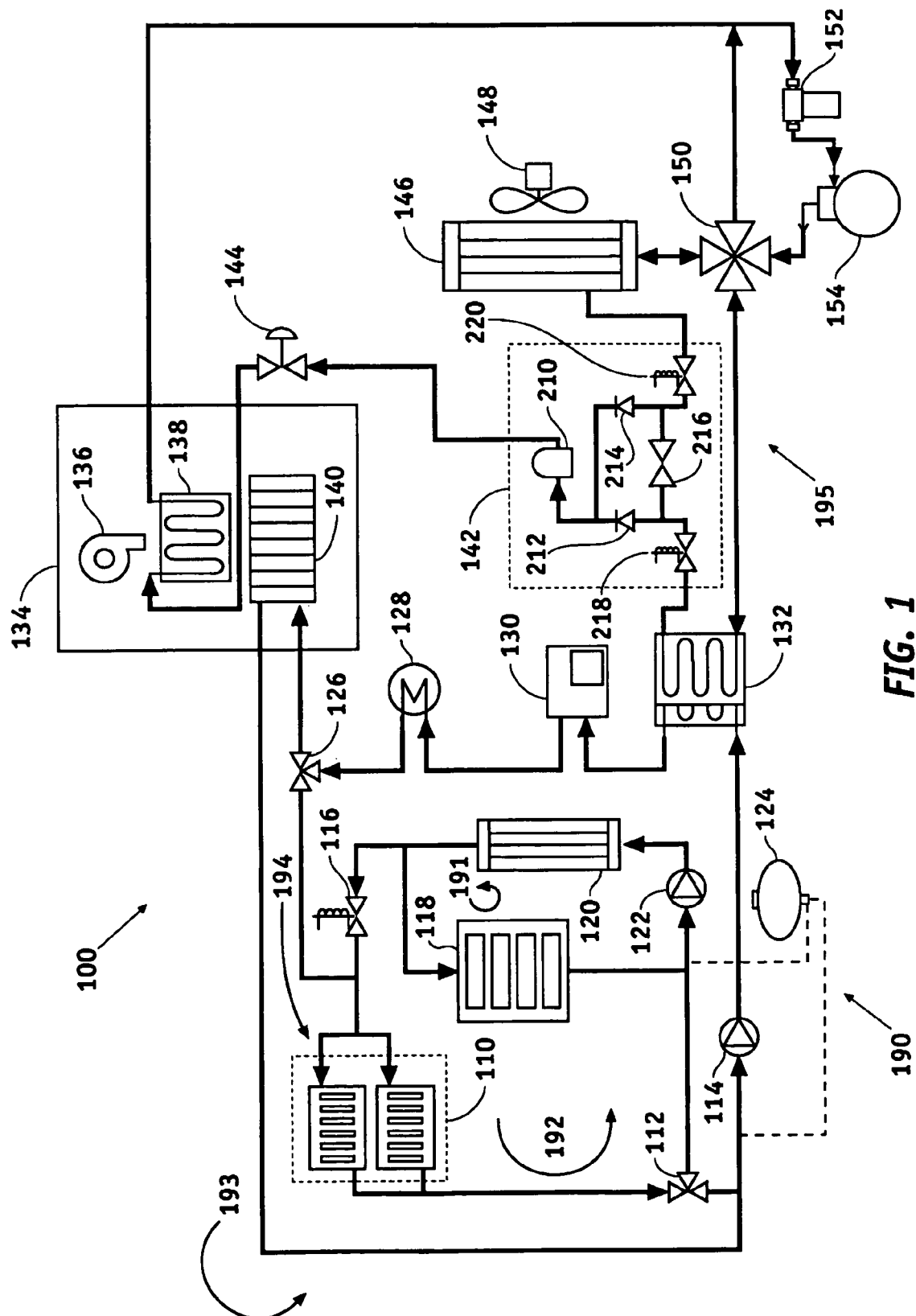
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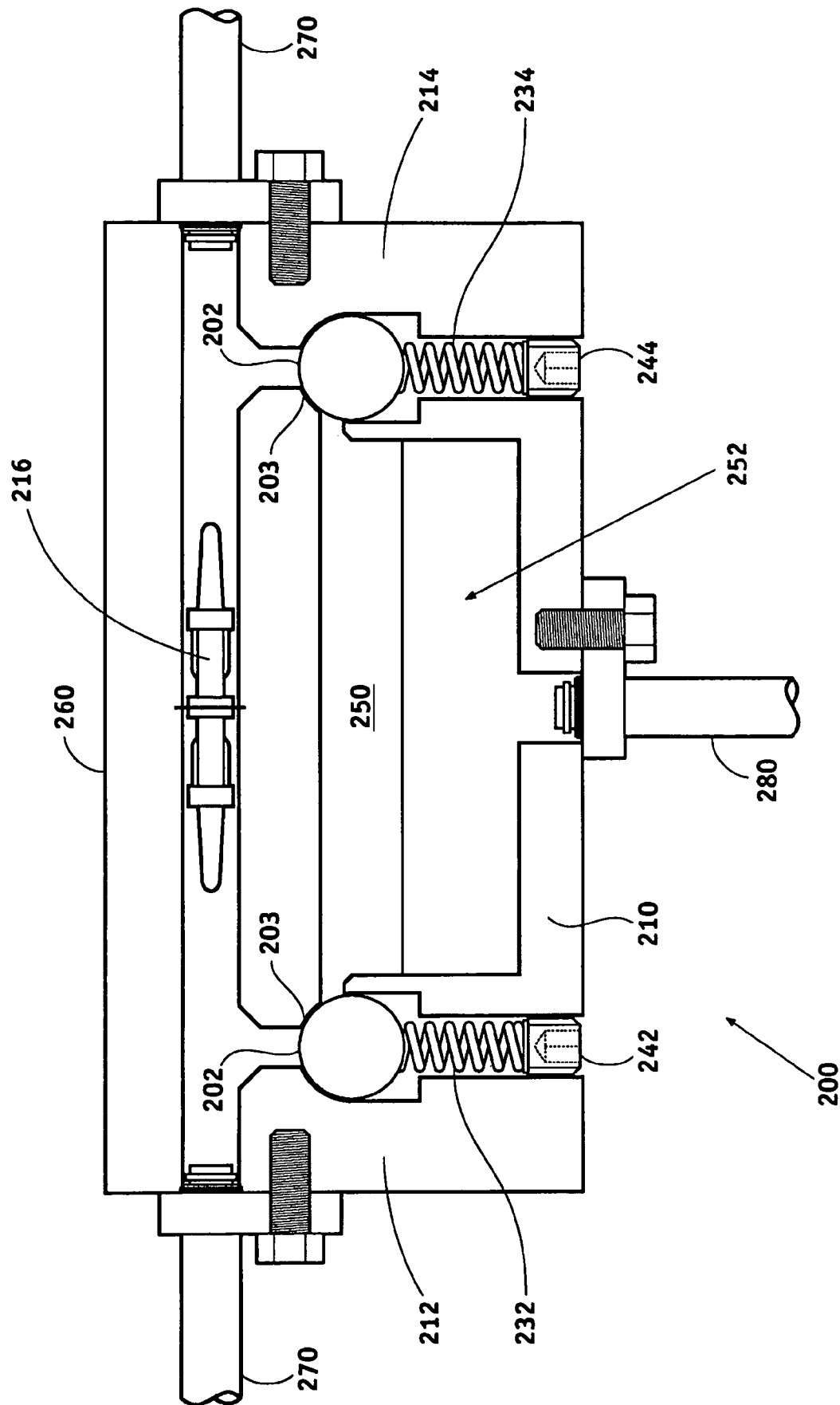
(57) **ABSTRACT**

The integrated automotive HVAC/PTC system of the present invention includes a bi-fluidic heat exchanger between an air conditioning subsystem and a heating subsystem which enables heat extracted during dehumidification of the ventilation air to be transferred into dehumidified ventilation air. The HVAC/PTC system includes reconfigurable coolant loops and reconfigurable refrigerant loops, some of which act in concert and some of which may be isolated. Power train components, including the power supply, may be grouped by heat transfer requirements and may be cooled or heated as needed. Power train cooling is accomplished with coolant in the heating subsystem chilled by the air conditioning system.

**4 Claims, 2 Drawing Sheets**







**FIG. 2**

## 1

FULL FUNCTION VEHICLE HVAC/PTC  
THERMAL SYSTEM

## BACKGROUND OF THE INVENTION

## 1. Technical Field

The present invention relates generally to the field of motor vehicle heating, ventilation, and air conditioning (HVAC) systems and to vehicle power train cooling (PTC) systems and more particularly to a hybrid thermal control system for vehicles.

## 2. Background Art

Although the traditional internal combustion engine is still the most widely accepted power plant for mainstream motor vehicles, other types of vehicles are making inroads into the consumer marketplace. For example, electric and hybrid electric vehicles are becoming increasingly popular for certain consumer segments. Similarly, fuel cell engines and high-efficiency diesel engines are also growing in popularity as attractive alternatives to the standard gasoline powered engine. As automakers seek to accommodate these various trends in consumer buying habits, the process of designing and manufacturing vehicles that incorporate these new engines is also changing.

For example, in order to meet the rapidly growing demand for electric vehicles, many automakers are seeking to "retrofit" existing internal combustion engine vehicle designs with electric engines. This process includes changing out the engine and related components as necessary to accommodate the change in propulsion systems. Obviously, the manufacturer would like to change as few components as necessary in order to minimize costs and reduce the amount of time that it takes to get a new electric powered vehicle into production. While many of the components can be the same, regardless of the type of engine, certain components may be removed or added when updating an existing vehicle design to accommodate a battery powered engine. One area where this is most noticeable is the HVAC system for the vehicle.

Specifically, while traditional internal combustions engines generate excess heat that can be used for the various heating needs of the vehicle, such as heating the passenger cabin during cooler weather, most electric vehicle engines do not generate much excess heat. Similarly, the cooling requirements for an electric vehicle are also different in that cooling may be provided for certain additional components such as the electric vehicle's batteries. In addition, since many electric vehicles utilize heat pumps, different HVAC components may be added to a vehicle when an electric engine is to be installed. This variation in heating and cooling requirements for different types of engines translates to additional design and manufacturing time as well as increased cost for introducing new vehicles into the marketplace. Accordingly, to the extent possible, manufacturers seek additional opportunities to quickly and efficiently update existing vehicle designs and to use existing subsystems to accommodate new and emerging engine technologies.

In view of the foregoing, it should be appreciated that it would be desirable to provide methods and apparatus for minimizing the amount of time and money required by automakers to re-design existing vehicles for new and emerging engine technologies. Specifically, the ability to minimize design changes can provide the manufacturer with manufacturing flexibility, increased production capacity and shorten time to market. In addition, a single thermal system, adaptable to meet all of a vehicle's thermal requirements, would be desirable. Furthermore, additional desirable fea-

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tures will become apparent to one skilled in the art from the foregoing background of the invention and following detailed description of a preferred exemplary embodiment and appended claims.

## SUMMARY OF THE INVENTION

The present invention comprises a full-function vehicle thermal system further comprising a refrigerant-based automotive air conditioning subsystem which is reconfigurable to create one of a plurality of possible refrigerant loops, wherein each refrigerant loop of the plurality of possible refrigerant loops comprises a bidirectional orifice separator.

## BRIEF DESCRIPTION OF THE DRAWINGS

The preferred exemplary embodiments of the present invention will hereinafter be described in conjunction with the appended drawing, where like designations denote like elements, and:

FIG. 1 is a schematic block diagram of an HVAC/PTC thermal system in accordance with an exemplary embodiment of the full function vehicle HVAC/PTC thermal system; and

FIG. 2 is a vertical section view through an exemplary bidirectional orifice separator.

## DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

FIG. 1 shows an exemplary embodiment of a full-function vehicle HVAC/PTC thermal system **100**, comprising an integrated heating, ventilation, air conditioning and power train cooling (HVAC/PTC) system. Thermal system **100** may also provide heating for some power train components **118** and **110**. The connections joining the various components of system **100** may generally be characterized as tubes, channels, or piping used to transfer various coolants or refrigerants from one location to another within thermal system **100**. In some instances the refrigerant is in a liquid state and in other places the refrigerant will be in a gaseous state with the refrigerant changing states to provide a thermal transfer mechanism. Thermal system **100** comprises a refrigerant-based air conditioning subsystem, a coolant-based heating subsystem, and integrating components.

Power train components **110** and **118** comprise channels and/or plenums for coolant. Hereinafter, channeling coolant to a power train component, by any means, is to be understood to refer to channeling coolant to the channels and/or plenums in that power train component. Each of power train components **118** and **110** may represent a plurality of power train components.

Thermal system **100** comprises a refrigerant-based automotive air conditioning subsystem **195** integrated with a coolant-based automotive heating subsystem **190**. The refrigerant-based air conditioning subsystem **195** comprises an evaporator **138** in HVAC unit **134**, an outside air heat exchanger (OEX) **146** with fan assembly **148**, an accumulator **152**, a compressor **154**, a 4-way reversing valve **150**, a refrigerant side of a bi-fluidic heat exchanger (BEX) **132**, bidirectional orifice separator **142**, and a thermostatic expansion valve (TXV) **144**. HVAC unit **134** comprises a blower fan **136**, an evaporator **138**, a heater core **140**, and ductwork comprising blend actuators. The heater core **140** is part of the heating subsystem. Blower fan **136** blows ventilation air over evaporator **138**, which cools and dehumidifies the ventilation air. During the dehumidification process, heat

from the blown ventilation air may be transferred into the evaporator **138** and into the refrigerant circulating through the evaporator **138**. The cooled dehumidified ventilation air may be propelled further to cross over the heater core **140**. Heater core **140** transfers heat into the cooled dehumidified ventilation air from the hot coolant circulating through the heater core **140**. As will be seen in more detail below, heat transferred from the ventilation air into the refrigerant during dehumidification may be further transferred into the coolant and then back into the cooled dehumidified ventilation air. Blend actuators in the HVAC unit **134** determine the mixture of ventilation airs (i.e., inside air with outside air, heated dehumidified air with unheated dehumidified air, etc) in response to user inputs.

The coolant-based automotive heating subsystem **190** comprises heater core **140**, coolant pumps **114** and **122**, heat exchanger **120**, a coolant reservoir **124**, valves **112**, **116**, and **126**, and components which potentially transfer heat into the circulating coolant. Potentially heat-transferring components comprise a fuel operated heater **130**, an electrical coolant heater **128**, a coolant side of the bi-fluidic heat exchanger (BEX) **132**, and power train components **118**, including power supply **110**. Power supply **110** may comprise a battery, a fuel cell, a capacitor, or a capacitor bank. Other exemplary power train components **118** comprise a motor, a power inverter module, a high voltage interface box, and an auxiliary power module. Heat transfer between the potentially heat-transferring components **110**, **118**, **128**, **130**, and **132** may be via thermal conduction into coolant circulating through plenums or channels thermally connected to the components **110**, **118**, **128**, **130**, and **132**. BEX **132** comprises a refrigerant side having a refrigerant channel, or coil, a coolant side having a coolant channel, or coil, and thermally conductive pathways between the refrigerant and the coolant.

Each of the subsystems **190**, **195** may be reconfigurable to create a plurality of coolant loops and refrigerant loops, respectively. The system **100** may best be described in terms of the loops.

Subsystem **190** comprises a continuous power train cooling loop **191** for power train components **118**. Power train components **118** may be divided and isolated physically and thermally based upon different heat transfer requirements. In exemplary embodiment **100**, power train components **118** may represent power train components which need constant cooling, while power train components **110** may represent components which need occasional cooling and occasional heating, depending upon environmental factors. For example, power train components **118** may include the motor and power conditioning components, and power train components **110** may be a power supply **110** such as batteries **110**. Heat exchanger **120**, which may be radiator **120**, power train components **118**, and radiator coolant pump **122** may comprise a closed coolant loop **191** that may operate continuously to cool only power train components **118**.

Coolant shutoff valve **116** may open to extend the closed loop **191** to form loop **192** by opening a channel between radiator **120** and power train components **110** when heater/battery 3-way valve **126** and coolant pumps 3-way valve **112** close the channels to heater core **140**. Loops **191** and **192** may operate simultaneously. A plurality of such loop extensions, using a plurality of coolant shutoff valves **116** and coolant pumps 3-way valves **112** may be used in alternate embodiments having power train components **118** and **110** with 3 or more distinct heat transfer requirements. In some embodiments, radiator **120** may transfer heat into the pas-

senger cabin of the vehicle during very cold weather and transfer heat to outside air in warm weather.

With the power train components **118** and **110** in closed loop configurations **191** and **192**, heater core **140** comprises part of a coolant loop **193**. Loops **191**, **192** and **193** may operate simultaneously. Coolant loop **193** further comprises BEX pump **114**, the coolant side of BEX **132**, fuel operated heater **130**, electrical coolant heater **128**, and heater/battery 3-way valve **126**. Coolant flows out of the heater core **140** to the BEX pump **114**, which pumps coolant through the coolant side of BEX **132**. BEX **132** comprises a bi-fluidic heat exchanger, comprising a coolant channel, or coil, thermally connected to a refrigerant channel, or coil. For example, the refrigerant coil may be welded directly to the coolant coil for heat transfer through the coil walls. For another example, the coils may be connected by thermally conductive webbing. The present invention contemplates a wide range of approaches in the design of the BEX **132**.

When loop **193** is operating, heat from the refrigerant may be transferred into the coolant in BEX **132**. The coolant may continue to circulate through the fuel-operated heater **130** and the electrical coolant heater **128**. The coolant heaters **128** and **130** are optional. In extremely cold weather, the heat transferred into the coolant in the BEX **132** may not be sufficient to provide comfortably warm air in the passenger cabin. In such cases, the coolant may be actively heated by fuel-operated coolant heater **130** or electrical coolant heater **128**. The heated coolant circulates through heater/battery 3-way valve **126** and back to the heater core **140** where heat may be transferred to blown ventilation air in HVAC unit **134**. One or both of the power train component **118** and/or **110** coolant loops **191** and/or **192** may run concurrently with the passenger cabin heating loop **193**.

In some configurations of the HVAC unit **134**, blend actuators within the HVAC unit **134** may direct air heated by the heater core **140** in loop **193** to a destination other than the passenger cabin. For example, on a hot, dry day, when a first or fourth refrigerant loop (discussed more fully below) may be transferring heat into coolant through the BEX **132**, at least a portion of the heated ventilation air may be directed to outside air. Likewise, HVAC unit **134** may receive input air from either the passenger cabin, another defined interior space, the outside ambient atmosphere, or some combination thereof.

In the loop **194** configuration, heater/battery 3-way valve **126** channels coolant to power train components **110** instead of heater core **140**. Coolant pumps 3-way valve **112** channels coolant from the power train components **110** to the BEX pump **114**, which pumps the coolant through the BEX **132** and coolant heaters **130** and/or **128**, and then through battery/heater 3-way valve **126**. Loop **194** may be used for transferring heat from refrigerant in the BEX **132** to power train components **110**. Note that the coolant loop **191** may continue to run and cool the remaining power train components **118** while the power train components **110** are being heated. For example, in an embodiment using batteries as power train components **110**, the batteries **110** may require heating during extremely cold weather or at start-up. Loop **194** may also be used, depending on the configuration of subsystem **195**, to transfer heat to the refrigerant in the BEX **132**. In this configuration, loop **194** may be used to cool power train components **110**. For example, after start-up, batteries **110** may require cooling.

In an alternate embodiment, power train components **118** may be fluidically connected in series to a coolant-to-coolant heat exchanger (not shown) between BEX **132** and BEX pump **114**, allowing the heat from the power train compo-

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nents 118 to be used for warming the passenger cabin through heater core 140. In variations of this alternate embodiment, power train components 118 may be configured to transfer heat into any segment of the coolant heating line 114, 132, 130, 128, 126 or out of the coolant heating line 114, 132, 130, 128, 126, as needed. If the heat transferred from the power train components 118 is insufficient to meet cabin-heating needs, coolant heaters 128 and 130 may compensate. If the heat transferred from the power train components 118 is excessive, the power train components 118 can be switched out of the coolant heating line 114, 132, 130, 128, 126. In a further variation of this alternate embodiment, radiator coolant pump 122 may be turned off when heat is being transferred from second plenums. In a particular embodiment preferred for strong hybrid vehicles, the coolant heater 130 may be a heat exchanger for exchanging heat between the power train components 118 and the coolant.

In some embodiments, all power train components 188 and 110 may be alternately heated, cooled, or neither heated nor cooled. In yet other embodiments, all power train components 188 and 110 may only be cooled or not cooled. In still other embodiments, all power train components may only be heated or not heated.

The air conditioning subsystem comprises compressor 154, 4-way reversing valve 150, outside air heat exchanger (OEX) 146 with fan assembly 148, bidirectional orifice separator 142 comprising valves 218 and 220, thermostatic expansion valve (TXV) 144, evaporator 138, and accumulator 152. As an alternate parallel path to the OEX 146, the air conditioning subsystem further comprises a refrigerant side of the BEX 132. Except for the bidirectional orifice separator 142, the components of the air conditioning system are individually well known off-the-shelf components. The use of off-the-shelf components is an advantage of the design of the full function vehicle HVAC/PTC thermal system 100.

The bidirectional orifice separator 142 is a novel device enabling, in concert with 4-way reversing valve 150, parallel heat exchangers 132 and 146 to be used alternately as condensers or in combination as evaporator-condenser pairs, either OEX 146 or the refrigerant side of BEX 132 serving either as the condenser or as the evaporator. The effect of the bidirectional orifice separator 142 may be determined by the states of transfer valves 218 and 220. Transfer valves 218 and 220 comprise shut off valves in a reversible flow channel. Transfer valves 218 and 220 may be both open or one open and one closed, depending on the desired result.

When both transfer valves 218 and 220 are open, refrigerant will flow through orifice tube 216, which expands the refrigerant. Expanding refrigerant produces refrigerant with a lower pressure and a lower temperature and comprises a preliminary step to evaporating the refrigerant. Orifice tube 216 comprises a bidirectional orifice tube, so the flow of refrigerant may be from either direction. The direction of refrigerant flow may be determined by the state of the 4-way reversing valve 150.

The 4-way reversing valve 150 is a bi-stable valve which receives compressed hot refrigerant from compressor 154 through a dedicated input channel, that channel indicated in FIG. 1 by the arrow head on the line from compressor 154. Compressor 154 may be an electrical compressor 154 and may include a compressor motor controller. The 4-way reversing valve 150 also has a dedicated output channel to a suction side of compressor 154. In a first bi-stable state, the 4-way reversing valve 150 channels hot compressed refrigerant to the OEX 146 and fluidically connects the suction

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side of compressor 154 to the BEX 132. In a second bi-stable state, the 4-way reversing valve 150 channels hot compressed refrigerant to the BEX 132 and fluidically connects the suction side of compressor 154 to the OEX 146. The configuration of the air conditioning subsystem 195 in either bi-stable state of the 4-way reversing valve 150 depends on the states of transfer valves 218 and 220.

A first refrigerant loop may be formed when the BEX 132 is receiving compressor 154 outflow, valve 218 is open, and valve 220 is closed. The received refrigerant may be condensed in the refrigerant side of the BEX 132, transferring heat to the coolant side of BEX 132. The condensed refrigerant moves through transfer valve 218 and check valve 212 to receiver 210, which makes a liquid component of the condensed refrigerant available to TXV 144. Liquid refrigerant flows from TXV 144 to the evaporator 138 in HVAC unit 134. The evaporator 138 transfers heat from the ventilation air to the refrigerant, which evaporates. Heat loss in the ventilation air creates cooled and dehumidified ventilation air. The evaporated refrigerant flows to the suction side of compressor 154 through accumulator 152, which completes the first refrigerant loop.

OEX 146 may be isolated from the first refrigerant loop. Although one port of the OEX 146 may be fluidically connected to the suction side of compressor 154 through accumulator 152, no refrigerant flows from OEX 146 because the other port of OEX 146 is fluidically connected to valve 220. Valve 220 is closed, leaving the compressor 154 to suck on a closed valve 220, which produces no flow. The suction from compressor 154 is instead applied to the output of evaporator 138.

The first refrigerant loop may be used in concert with loop 193. Loop 193 receives heat from the refrigerant, which heat may be transferred to the coolant in the BEX 132. The heat may be discharged from loop 193 in the heater core 140, where the heat may be transferred to cooled, dehumidified ventilation air to make warmer dehumidified ventilation air. Accordingly, the first refrigerant loop and loop 193 act in concert to extract heat from the ventilation air during cooling and dehumidification and return the extracted heat to the cooled dehumidified air. The reuse of the heat of dehumidification to warm the dehumidified air provides improved efficiency of operation for thermal system 100.

The first refrigerant loop may also be used in concert with loop 194. Loop 194 receives heat from the BEX 132 and uses it to warm power train components 110, such as batteries 110. Heat from BEX 132 may make it unnecessary to consume fuel and/or electricity in coolant heaters 130 and 128, thereby improving the efficiency of thermal system 100.

The first refrigerant loop may be used concurrently with loops 191, 192 and 193 if loop 194 is not in use. Coolant heaters 128 and 130 are normally OFF when the first refrigerant loop is running. However, if the heat transferred through the BEX 132 is inadequate for cabin heating needs, then coolant heaters 128 and 130 may be ON.

A second refrigerant loop may be formed when the OEX 146 is receiving compressor 154 outflow, transfer valve 218 is closed, and transfer valve 220 is open. In this configuration, the BEX 132 may be isolated from the second refrigerant loop just as the OEX 146 may be isolated in the first refrigerant loop. When the BEX 132 is isolated, there may be no integrated activity between subsystems 190 and 195. Accordingly, the second refrigerant loop is very nearly a conventional air conditioning loop, differing only in that it is switched to by, and includes elements 220, 214, 210 of, the bidirectional orifice separator 142. The second refrigerant

ant loop may be used concurrently with loops **191**, **192**, and **193** or with loops **191** and **194**, or with loops **191** and **193**. Coolant heaters **128** and **130** may be ON when the second refrigerant loop is in use.

A third refrigerant loop may be formed when both transfer valves **218** and **220** are open and the OEX **146** is receiving compressor **154** outflow through 4-way reversing valve **150**. In this configuration, OEX **146** acts as a condenser. OEX **146** transfers heat to the outside air and condensed refrigerant flows out of OEX **146**, through valve **220**, through bidirectional orifice tube **216**, through valve **218** and through the refrigerant side of BEX **132** to the suction side of compressor **154** through accumulator **152**. Bidirectional orifice tube **216** expands the condensed refrigerant. The refrigerant side of BEX **132** acts as an evaporator, cooling the coolant side of BEX **132**.

Neither the third refrigerant loop nor the fourth refrigerant loop, discussed in more detail below, isolates evaporator **138**. In the third refrigerant loop, enough condensed refrigerant flows through check valve **214** to receiver **210** to keep the TXV **144** supplied with liquid refrigerant. TXV **144** comprises an integral temperature sensor which attaches to the output channel of evaporator **138**. Conventionally, TXV **144** has a continuous range of flow restrictions between fully open and closed. The flow restriction varies automatically as a function the temperature at the output of evaporator **128** and a pre-selected setting. TXV **144** acts to maintain a constant temperature difference between the evaporator **138** output and the pre-selected setting by providing more refrigerant to evaporator **138** when the output temperature rises and less when the output temperature falls. The state of TXV **144** determines the demand for refrigerant from receiver **210** in bidirectional orifice separator **142**. The demand on receiver **210** affects the pressure at the output of the check valves **212** and **214**. In the third and fourth refrigerant loops (both transfer valves **218** and **220** open), the pressure at the output of the orifice tube **216** may be determined by the suction of the compressor **154**. If the TXV **144** increases flow to the evaporator **138**, the pressure difference across check valve **214** (third refrigerant loop) will increase and more of the refrigerant will flow through the check valve **214** and less refrigerant will flow through the orifice tube **216**. Accordingly, in any refrigerant loop, the TXV **144** will always have sufficient coolant to operate evaporator **138**. Any of the refrigerant loops may extract heat from the ventilation air in HVAC unit **134**.

The third refrigerant loop may be used in concert with loop **194** to cool power train components **110**. The third refrigerant loop dumps the heat extracted from dehumidification to the outside air through OEX **146** as a necessary sacrifice to keep critical power train components **110** cool. Loop **191** may run concurrently with the third refrigerant loop and loop **194**. Coolant heaters **128** and **130** are OFF when the third refrigerant loop is used with loop **194**.

The fourth refrigerant loop may be formed when both transfer valves **218** and **220** are open and the BEX **132** is receiving compressor **154** outflow. In this configuration, the refrigerant side of BEX **132** acts as a condenser and condensed refrigerant flows out of the refrigerant side BEX **132**, through valve **218**, through bidirectional orifice tube **216**, through valve **220** and through OEX **146** to the suction side of compressor **154** through accumulator **152**. Bidirectional orifice tube **216** expands the condensed refrigerant. The OEX **146** acts as an evaporator, cooling the outside air. The refrigerant side of BEX **132** transfers heat to the coolant side of BEX **132**.

The fourth refrigerant loop may be used with loop **193** to recycle heat transferred into coolant through the BEX **132**. Heat may then be transferred through the heater core **140** to warm the ventilation air. A portion of the heat transferred through the BEX **132** in the fourth refrigerant loop comprises heat originally transferred into evaporator **138** during dehumidification. That originally transferred heat may be contained in the refrigerant which mixes in accumulator **152** with refrigerant from the OEX **146** and may be sent into the refrigerant side of BEX **132** by the compressor **154**.

The fourth refrigerant loop may be used in concert with loop **194** to heat power train components **110**. Loop **191** may run concurrently with the fourth refrigerant loop. Loop **192** may run concurrently with the fourth refrigerant loop if loop **194** is not running, as when the heat transferred through the BEX **132** is routed to the heater core **140**. Coolant heaters **128** and **130** may be ON when the fourth coolant loop is running.

Outside air heat exchange unit (OEX) **146** and fan assembly **148** are used to effectuate heat transfers from thermal system **100** to the ambient atmosphere outside the vehicle containing thermal system **100**. In an embodiment, the fan assembly **148** may comprise a variable speed fan, the fan speed responsive to vehicle speed and cooling needs of thermal system **100**.

In a particular embodiment, the 4-way reversing valve **150** comprises a valve integral to the bidirectional orifice separator **142**. In a variation of the particular embodiment, an electronic valve controller may also be integrated with the 4-way reversing valve **150** and the bidirectional orifice separator **142**.

FIG. 2 shows a vertical section of an exemplary embodiment of a bidirectional orifice separator **200** comprising a bidirectional orifice tube **216** fluidically connected to the inputs of check valves **212** and **214** which control the entry of refrigerant into receiver **210**. Check valves **212** and **214** and receiver **210** are labeled in the drawing by reference to portions of structure encasing them. Check valves **212** and **214** may comprise ball **202** and seat **203** valves, but other types of check valves are also contemplated. Check valves **212** and **214** may be biased by biasing mechanisms **232** and **234**, respectively. The bias may be an adjustable bias. For example, screw-type adjustments **242** and **244** may be employed to bias the compression of spring biasing mechanisms **232** and **234**. Receiver **210** comprises a chamber for containing refrigerant **250** and **252**. Removable cover **260** provides access to the orifice tube **216** for maintenance.

Channels **270** may be fitted with valves **218** and **220** (FIG. 1). Refrigerant may enter through either or both channels **270**. If fluid enters from one channel **270** and the other channel **270** is closed, there is no flow through the bidirectional orifice tube **216**. Refrigerant may flow through the check valve **212** or **214** closest to an inlet channel **270** and into receiver **210**. In receiver **210**, the refrigerant will separate into liquid refrigerant **252** and gaseous refrigerant **250**. Liquid refrigerant **252** may flow out of bottom of the receiver **210** and through channel **280** to a TXV **144** (FIG. 1).

If refrigerant flows into one (inlet) channel **270** and out the other (outlet) channel **270**, then refrigerant will flow through the bidirectional orifice tube **216**. The refrigerant flowing through the bidirectional orifice tube **216** will be expanded to a lower pressure and temperature before exiting through the outlet channel **270**. The bidirectional orifice tube **216** creates some flow resistance and back pressure at the check valve **212** or **214** nearest the inlet channel **270**. The

check valve **212** or **214** nearest the inlet channel **270** is adjusted to allow some refrigerant into the receiver **210**.

The bidirectional orifice separator **200** is adapted for reversible flow, enabling heat exchangers fluidically connected to channels **270** (e.g. **132** and **146** of FIG. 1) to operate as a reversible evaporator-condenser pair. The bidirectional orifice separator may also operate with only one heat exchanger.

In summary, the exemplary embodiments of the present invention provide a thermal system that utilizes many existing components from more traditional internal combustion engines while accommodating various new and more efficient engine technologies. Additionally, vehicle range can be improved because energy normally lost as waste heat can be more efficiently utilized by the thermal system. Another benefit is the capability of using a single thermal system to provide temperature control for passenger comfort as well as vehicle-related heating and cooling needs for the engine, motor, electric batteries, etc. A novel device, a bidirectional orifice separator **142**, enables the flexibility the system needs to meet such a broad set of requirements.

From the foregoing description, it should be appreciated that an apparatus is provided for an automotive thermal system adapted to new and emerging engine technologies. While an exemplary embodiment has been presented in the foregoing detailed description of the exemplary embodiment, it should be appreciated that a vast number of variations in the embodiments exist. For example, although the various embodiments of the present invention have been described in the context of electric vehicles, those skilled in the art will recognize that the principles and techniques of the exemplary embodiments are readily adaptable for other engine technologies such as hybrid electric vehicles, fuel cell vehicles, high-efficiency diesel vehicles, and the like.

It should also be appreciated that the exemplary embodiments are only examples, and are not intended to limit the scope, applicability, or configuration of the invention in any way. Rather, the foregoing detailed description provides those skilled in the art with a convenient road map for implementing the exemplary embodiments of the invention. It should also be understood that various changes may be made in the function and arrangement of elements described in the exemplary embodiments without departing from the spirit and scope of the invention as set forth in the appended claims. For example, any number of power train component cooling and heating loops may be included to deal with for an equal number of different heating and cooling requirements.

The invention claimed is:

**1.** A thermal system for an electrically-powered vehicle having a power train, the thermal system comprising:

- a reconfigurable refrigerant-based automotive air conditioning system to selectively create a plurality of possible refrigerant loops, the refrigerant-based automotive air conditioning system comprising:
  - an evaporator having refrigerant channels thermally connected to ventilation air and configurable to receive previously cooled refrigerant, the evaporator operable to cool and dehumidify the flow of ventilation air;
  - a bi-fluidic heat exchanger having refrigerant channels thermally coupled to coolant channels;

an outside air heat exchanger;

a bidirectional orifice separator within at least one refrigerant loop of the plurality of possible refrigerant loops, the bidirectional orifice separator comprising:

- a first shutoff valve fluidically coupled to the bi-fluidic heat exchanger;
- a second shutoff valve fluidically coupled to the outside air heat exchanger; and
- a bidirectional orifice tube coupled in series between the first shutoff valve and the second shutoff valve for expanding refrigerant when the first and second shutoff valves are open;

a compressor;

an accumulator fluidically coupled to an input of the compressor; and

a 4-way reversing valve configured to receive compressed refrigerant from the compressor and operable to discharge compressed refrigerant into a selected one of the bi-fluidic heat exchanger and the outside air heat exchanger and to receive refrigerant from the non-selected one of the bi-fluidic heat exchanger and the outside air heat exchanger to discharge refrigerant from the non-selected one of the bi-fluidic heat exchanger and the outside air heat exchanger to the accumulator; and

a reconfigurable liquid-coolant-based automotive heating system to selectively create a plurality of possible coolant loops, wherein the refrigerant-based automotive air conditioning system and the liquid-coolant-based automotive heating system are configured to operate concurrently and in concert.

**2.** A thermal system according to claim **1** wherein the heating system comprises:

- a heater core; and
- a 3-way valve for transferring coolant to the heater core.

**3.** A thermal system according to claim **2** wherein the evaporator is configured to receive refrigerant previously cooled in a bi-fluidic heat exchanger, the bidirectional orifice separator including the first shutoff valve, configured to permit flow of refrigerant into the bidirectional orifice separator, the second shutoff valve configured to prevent flow of refrigerant into the bidirectional orifice separator, and the 4-way valve configured to select the bi-fluidic heat exchanger, the refrigerant-based automotive air conditioning system thus configured comprising a first refrigerant loop of the plurality of refrigerant loops operable to remove heat from ventilation air during dehumidification and transfer heat through the bi-fluidic heat exchanger to a coolant loop of the coolant-based heating system.

**4.** A thermal system according to claim **3**, wherein the coolant loop of the plurality of coolant loops comprises a first coolant loop coupled in series between the heater core and the bi-fluidic heat exchanger, the 3-way valve configured to discharge coolant to the heater core, and the heater core configured to receive coolant from the bi-fluidic heat exchanger.