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United States Patent Application Publication	20250264256
Kind Code	A1
Publication Date	August 21, 2025
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SYSTEM AND METHOD OF MONITOR QUALITY OF A REFRIGERANT IN A COOLING SYSTEM

Abstract

A refrigerant quality sensor includes an elongated sensor housing comprising a first end wall and a second end wall and at least one side wall extending between the first end wall and the second end wall. A refrigerant inlet and a refrigerant outlet are disposed in the at least one side wall. A light source is disposed at the first end wall. A photosensor is disposed at the second end wall. The photosensor generates an electrical signal corresponding to a quality of refrigerant within the elongated sensor housing.

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Family ID: **1000007696332**

Appl. No.: **18/581524**

Filed: **February 20, 2024**

Publication Classification

Int. Cl.: **F25B49/02** (20060101)

U.S. Cl.:

CPC **F25B49/02** (20130101); F25B2500/18 (20130101); F25B2600/13 (20130101); F25B2700/00 (20130101)

Background/Summary

FIELD

[0001] The present disclosure relates generally to refrigerant-based cooling systems and, more specifically, to a system and method for monitoring the quality of the refrigerant in a two-phase cooling system.

BACKGROUND

[0002] Vehicles with electric propulsion systems are becoming increasingly more common. Some electrically propelled vehicles include an electric drive motor at each wheel of the vehicle, and some electrically propelled vehicles include a front electric drive motor for rotating the front wheels of the vehicle and a rear electric drive motor for rotating the rear wheels of the vehicle. In either case, the electric drive motors may include a power inverter device that is configured to convert DC power supplied by a battery of the vehicle to AC power for use by the electric drive motor to provide a motive force for the wheels.

[0003] The electric drive motors, power inverter devices, and battery generate heat during use thereof. As a result, the electric drive motors, power inverter devices, and battery may require cooling during use thereof. Methods of cooling the electric drive motors and power inverter devices currently include using a cooling system having a dedicated heat exchanger that circulates a coolant that may be composed of a mixture of ethylene glycol and water through or around the electric drive motor (to cool a lubricant contained in the electric drive motor) and power inverter device. Methods of cooling the battery currently may include using a thermal gel that draws heat from cells of the battery to a cooling plate attached to or located proximate the battery, where the heat is then removed via forced convection using a coolant that may be similar to that used to cool the electric drive motor and power inverter device (e.g., a mixture of ethylene glycol and water). These systems require a chiller to remove heat from the coolant before it enters the electric drive motor, power inverter device, and battery. These methods of cooling these components, however, have relatively low controllability and, therefore, are slow reacting systems that do not permit increased or decreased cooling to be achieved as dynamically as may be required as the sophistication of these components increases.

[0004] Another type of system for cooling an electric vehicle is a refrigerant-based cooling system that uses refrigerant that is produced by a compressor and condenser in an energy-intensive process. The refrigerant changes between a liquid phase and a gas phase during the process. The liquid refrigerant is accumulated in liquid/vapor separators or reservoirs using a control metering system. The liquid refrigerant is then pumped through the heat exchanger to cool the main system components including but not limited to the cabin, electric drive motors, the battery and associated power electronics. The pressure in the separators and the associated heat exchanger loop are regulated to control the saturation temperature. Heat is removed from the hot elements via the latent heat of vaporization of the boiled refrigerant. Mixed phase refrigerant in liquid and vapor form returns to the liquid/vapor separator and reservoirs where the refrigerant in the gas phase exits and returns to the compressor where the gas phase is compressed and reduced to a liquid.

[0005] Compressors can be damaged if liquid is drawn in during operation. Conventional refrigerant systems are unable to sense the current location and phase state of their refrigerant charge and must compromise efficiency to ensure liquid refrigerant will never be ingested by the compressor. In addition, system design is restricted by this uncertainty. A control system with knowledge of the location and state of saturated refrigerant in a system enables the use of refrigerant in new ways, including separating liquid and gaseous refrigerant, and exploiting the relative properties of each. Examples of prior systems that are found in U.S. application Ser. No. 18/187,140 entitled Two-Phase Electric Cooling System for Electric Vehicles and U.S. application Ser. No. 18/417,442 entitled System And Method Of Pre-Loading A Two-Phase Cooling System For Electric Vehicles, the disclosures of which are incorporated by reference herein.

[0006] Laboratory systems may determine the pressure of liquid and some determine a phase distribution. Such systems are large, complex, fragile and expensive. Therefore, they are not suitable for automotive applications.

SUMMARY

[0007] In the present system, the refrigerant quality is monitored to prevent damage to the compressor when liquid instead of vapor is being communicated to the compressor.

[0008] In one aspect of the disclosure, a refrigerant quality sensor includes an elongated sensor housing comprising a first end wall and a second end wall and at least one side wall extending between the first end wall and the second end wall. A refrigerant inlet and a refrigerant outlet are disposed in the at least one side wall. A light source is disposed at the first end wall. A photosensor is disposed at the second end wall. The photosensor generates a sensed quality signal corresponding to a quality of refrigerant within the elongated sensor housing.

[0009] In another aspect of the disclosure, a method of operating a cooling system includes communicating refrigerant into an elongated sensor housing, directing light from a light source through the refrigerant in the elongated sensor housing, generating a sensed quality signal at a photodetector corresponding to a quality of the refrigerant within the elongated sensor housing, determining a target quality based on a heat load, and generating an actuator control signal based on a difference between a sensed quality signal and the target quality.

[0010] Further areas of applicability of the teachings of the present disclosure will become apparent from the detailed description, claims and the drawings provided hereinafter, wherein like reference numerals refer to like features throughout the several views of the drawings. It should be understood that the detailed description, including disclosed embodiments and drawings referenced therein, are merely exemplary in nature intended for purposes of illustration only and are not intended to limit the scope of the present disclosure, its application or uses. Thus, variations that do not depart from the gist of the present disclosure are intended to be within the scope of the present disclosure.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. **1** illustrates a vehicle according to a principle of the present disclosure;

[0012] FIG. **2** is a schematic representation of a cooling system and coolant loop that may be used to cool an electric drive motor, power inverter device, and battery of the electric vehicle illustrated in FIG. **1**;

[0013] FIG. **3** is a block diagrammatic view of a controller for controlling the fill levels while the fill levels of refrigerant in the separators while the vehicle is plugged in;

[0014] FIG. **4**A is a cross-sectional view of the refrigerant quality sensor.

[0015] FIG. **4**B is an end view of the light source end of the refrigerant quality sensor.

[0016] FIG. **4**C is an end view of the photosensor end of the refrigerant quality sensor.

[0017] FIG. **5** is a flowchart of a method for operating a system having a refrigerant quality sensor to disable the compressor.

DETAILED DESCRIPTION

[0018] Example embodiments will now be described more fully with reference to the accompanying drawings. The example embodiments are provided so that this disclosure will be thorough and will fully convey the scope to those who are skilled in the art. Numerous specific details are set forth such as examples of specific components, devices, and methods, to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to those skilled in the art that specific details need not be employed, that example embodiments may be embodied in many different forms and that neither should be construed to limit the scope of the disclosure. In some example embodiments, well-known processes, well-known device structures, and well-known technologies are not described in detail.

[0019] The terminology used herein is for the purpose of describing particular example embodiments only and is not intended to be limiting. As used herein, the singular forms “a,” “an,” and “the” may be intended to include the plural forms as well, unless the context clearly indicates otherwise. The terms “comprises,” “comprising,” “including,” and “having,” are inclusive and therefore specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. The method steps, processes, and operations described herein are not to be construed as necessarily requiring their performance in the particular order discussed or illustrated, unless specifically identified as an order of performance. It is also to be understood that additional or alternative steps may be employed.

[0020] When an element or layer is referred to as being “on,” “engaged to,” “connected to,” or “coupled to” another element or layer, it may be directly on, engaged, connected or coupled to the other element or layer, or intervening elements or layers may be present. In contrast, when an element is referred to as being “directly on,” “directly engaged to,” “directly connected to,” or “directly coupled to” another element or layer, there may be no intervening elements or layers present. Other words used to describe the relationship between elements should be interpreted in a like fashion (e.g., “between” versus “directly between,” “adjacent” versus “directly adjacent,” etc.). As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items.

[0021] Although the terms first, second, third, etc. may be used herein to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers and/or sections should not be limited by these terms. These terms may be only used to distinguish one element, component, region, layer or section from another region, layer or section. Terms such as “first,” “second,” and other numerical terms when used herein do not imply a sequence or order unless clearly indicated by the context. Thus, a first element, component, region, layer or section discussed below could be termed a second element, component, region, layer or section without departing from the teachings of the example embodiments.

[0022] Spatially relative terms, such as “inner,” “outer,” “beneath,” “below,” “lower,” “above,” “upper,” and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. Spatially relative terms may be intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as “below” or “beneath” other elements or features would then be oriented “above” the other elements or features. Thus, the example term “below” can encompass both an orientation of above and below. The device may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein interpreted accordingly.

[0023] Referring to FIG. **1**, an example of a specific environment for an optical refrigerant quality sensor is set forth. Quality refers to the presence of refrigerant liquid within the refrigerant vapor which may be measured and indicated in various ways including the percentage of liquid and vapor. The optical characteristics change relative to the amount of vapor and liquid in a sample. The optical refrigerant quality sensor set forth herein may be used in other refrigerant-based systems such a portable or stationary refrigeration units. Warehouse refrigeration and cooling systems may benefit from the teaching set forth herein. A vehicle **10** according to the present example is illustrated. The vehicle **10** in the illustrated embodiment is a hybrid vehicle including a vehicle body **11** that defines a cabin **17**, an electric motor **12** and associated power electronics **14**, an internal combustion engine **16**, a condenser **18**, a fuel source **20**, a battery **22**, a charger **24**, and a plurality of wheels **26**. If vehicle **10** is an electric vehicle rather than a hybrid vehicle, engine **16** and fuel source **20** may be omitted. As will be described in more detail below, condenser **18** is part of a cooling system **28** (FIG. **2**) that can be used to cool electric motor **12**, power electronics **14**, and battery **22**.

[0024] Before proceeding with the description of the cooling system **28**, it should be understood that while only a single electric motor **12** is illustrated in FIG. **1**, one skilled in the art will readily acknowledge and appreciate that vehicle **10** may be provided with a plurality of electric motors **12** and associated power electronics **14**. For example, the vehicle **10** may include a pair of electric motors **12** (e.g., as shown in FIG. **2**) that each include an associated electronics device **14**, with one of the electric motors **12** being configured to rotate the wheels **26** located a front of the vehicle **10** and the other electric motor **12** being configured to rotate the wheels **26** located at a rear of the vehicle **10**. Alternatively, vehicle **10** may include four electric motors **12** that each include an associated electronics device **14** with each wheel **26** having a dedicated motor **12** for rotation thereof.

[0025] A vehicle plug **29** may be used to plug the vehicle into a power source external to the vehicle to charge the battery **22**.

[0026] Referring now to FIG. **2**, cooling system **28** includes a coolant or refrigerant loop **30** that includes a plurality of coolant or refrigerant sub-loops **32**, **34**, **36**, and **38**. Components of coolant loop **30** that are utilized by each of the coolant sub-loops **32**, **34**, **36**, and **38** include a compressor **40**, condenser **18** located at a front of vehicle **10**, and an air moving device **42** such as a fan, which is configured to draw ambient air through condenser **18** so that heat transfer can occur between a refrigerant carried by coolant loop **30** and the ambient air. Compressor **40** and refrigerant can be any type of compressor or refrigerant known to one skilled in the art.

[0027] Sub-loop **32** generally is directed to cooling and/or heating an interior (e.g., cabin **17**) of vehicle **10**. Sub-loop **32** is configured to operate in at least two modes including a cooling mode where the interior of the vehicle **10** is cooled and a heating mode where the interior of the vehicle **10** is heated. In this regard, sub-loop **32** can operate as an air conditioner or a heat pump. In the illustrated embodiment of sub-loop **32**, the coolant that circulates through coolant system **28** travels through a suction line **44** to a suction inlet **46** of compressor **40**, which then compresses the refrigerant and discharges the compressed refrigerant through a discharge outlet **48** to a discharge line **50**. Discharge line **50** is connected to the condenser **18** ultimately to a tee joint **52** downstream to the condenser **18**. The tee joint **52** permits the compressed refrigerant to travel in the radiator outlet line **62** or to a first cabin heat exchanger inlet line **54** that is connected to a cabin heat exchanger **56** that is located within the interior of vehicle **10**.

[0028] The heat exchanger **56** has an expansion device with shut-off **56***a* and a second expansion device **56***b*. The liquid flowing through the heat exchanger, the expansion device **56***a* and the expansion device **56***b* is ultimately communicated through tee joint **58** which couples to the suction line **44** of the compressor **40**. The cabin has a cabin compressor **60** that has a suction inlet **61***a* and an outlet **61***b*. The cabin has a sub-loop **32***b* that is fluidically coupled from the coolant loop **30**. The heat exchanger **56** receives coolant in vapor form from the compressor **61** at a vapor inlet through the switching valves **63**. An outlet **65** from the heat exchanger **56** is communication with a switching a valve **66**. The switching valve **63** is in fluid communication with an inner condenser **67**. Ultimately, by controlling the switching valves **63**, **66**, a cooling or heating mode may be entered. Refrigerant from the switching valves **63** travels through the inner condenser **67** and to tee joint **68**. Refrigerant from the tee joint **68** travels in liquid form to the heat exchanger through a liquid inlet **69**. Fluid from the inner condenser **67** travels to an evaporator **70** through an evaporator inlet **70***a*. An evaporator outlet **70***b* travels to a fluid separator **71**. That is, the separator **71** has a reservoir **71***a* used for storing both liquid and vapor. The separator **71** may also have a pressure regulator **71***b*. The evaporator **70** cools and dries air entering the passenger compartment. Vapor is ultimately drawn through the compressor **61**. A tee joint **72** forms a loop with an expansion device with shutoff **73** that allows the refrigerant to travel back to the separator **71**. Because the compressor **61** generates heat, the hot refrigerant in vapor form travels back to the separator **71** through the expansion device with shutoff **73**. The sub-loops **32***b* thus forms a fluidically isolated heating or cooling loop depending on the position of the switching valves **63**, **66**.

[0029] Sub-loops **34** and **36** are designed to provide the refrigerant of cooling system **28** to a first drive assembly **94***a* and a second drive assembly **94***b*. Each drive assembly **94***a*, **94***b* includes an electric motor **12***a* and **12***b*, respectively, that have an associated power electronic module **14***a* and **14***b*, respectively, located proximate or attached thereto. Power electronic modules **14***a* and **14***b* may each be a power inverter device that is configured to convert DC power supplied by battery **22** of vehicle **10** to AC power for use by the electric drive motors **12***a*, **12***b* to provide a motive force to the wheels **26**.

[0030] As noted above, sub-loops **34** and **36** are substantially similar to each other or identical. Accordingly, the below description of these sub-loops will predominantly be directed to sub-loop **34**. Notwithstanding, to distinguish the features of sub-loop **34** from the features of sub-loop **36**, the reference numbers associated with sub-loop **34** will include the letter "a" (e.g., drive assembly **94***a*) and the reference numbers associated with sub-loop **36** will include the letter "b" (e.g., drive assembly **94***b*).

[0031] Sub-loop inlet line **43** is attached to a tee-joint **96** that directs the refrigerant to each of sub-loop **34** and sub-loop **36**. Specifically, tee-joint **96***a* directs the refrigerant to an inlet line **98***a* that is connected to a mass flow metering device **100***a*. Mass flow metering device **100***a* may be any type of mass flow metering device known to one skilled in the art. For example, mass flow metering device **100***a* may be a proportionally controlled valve that is actuated by using a solenoid, a stepper motor, or by rotating a worm gear. Mass flow metering device **100***a* can be used to control the amount of refrigerant that is permitted to reach drive assembly **94***a*, as will be described in more detail later.

[0032] After passing through mass flow metering device **100***a*, the refrigerant enters a mass flow metering device outlet line **102***a* that is connected to a separator **120***a* that is configured to store a portion of the refrigerant therein. The refrigerant may be in liquid for and or vapor form or both. Separator **120***a* is attached to a pump **104***a* via a first separator outlet line **121***a*. Pump **104***a* is configured to draw the refrigerant toward the sub-loop **34** from separator **120***a*. After exiting pump **104***a*, the refrigerant enters a drive assembly inlet line **106***a* that feeds the refrigerant to the drive assembly **94***a*. Drive assembly inlet line **106***a* is connected to a tee joint **108***a* that diverts the refrigerant to each of the electric drive motor **12***a* and power electronics module **14***a*.

[0033] Specifically, power electronics module **14***a* may be equipped with a jacket or heat sink that receives refrigerant from a power electronics module inlet line **110***a*. Similarly, electric drive motor **12***a* may be equipped with a jacket or heat sink that receives refrigerant from an electric drive motor inlet line **112***a*. Heat generated by electric drive motor **12***a* and power electronics module **14***a* may then be transferred to the refrigerant, which exits each of the electric drive motor **12***a* and power electronics module **14***a* through an electric drive motor outlet line **114***a* and power electronics outlet line **116***a*, respectively.

[0034] Outlet lines **114***a* and **116***a* are connected at tee joint **118***a* that is connected to a separator (e.g., accumulator) **120***a* by a separator inlet line **122***a*. When the refrigerant absorbs heat from electric drive motor **12***a* and power electronics module **14***a*, a portion of the refrigerant can undergo phase change from liquid to gas. Separator **120***a* includes a reservoir **124***a* that is configured to collect the liquid refrigerant from separator inlet line **122***a* (and also received from first mass flow metering device **100***a*) and return the liquid refrigerant back to pump **104**. Although first separator outlet line **121***a*, where the liquid refrigerant can again be used to cool electric drive motor **12***a* and power electronics module **14***a*. Meanwhile, the gaseous refrigerant received by separator **120***a* from separator inlet line **122***a* may be released from separator **120***a* through a pressure regulation valve **128***a* located atop separator **120***a*. After exiting pressure regulation valve **128***a*, the gaseous refrigerant enters a second separator outlet line **130***a* that is connected to a first tee joint **131***a* together with the separator outlet line **130***b*. Another tee joint **131***b* couples the tee joint **131***a* to the suction line **44** of compressor **40**.

[0035] Now description of the sub-loop **38** that is used to cool battery **22** will be described. Sub-loop **38** includes an inlet line **132** connected to tee joint **96***a* which is in fluid communication with tee joint **96**. Inlet line **98***b* of sub-loop **36** is ultimately fluidically connected to radiator outlet line **62** through tee joints **96** and **96***a*. Likewise, refrigerant from inlet line **132** is ultimately fluidically connected to radiator outlet line **62** through tee joints **96** and **96***a*. Inlet line **132** is provided to another mass flow metering device **134** that is connected to another separator **144** by mass flow metering device outlet line **138**, which provides the refrigerant to a pump **136** via a first battery separator outlet line **148**. Pump **136** feeds the refrigerant to a switching valve **140** that provides the coolant to a heat exchanger **23** of battery **22** when opened to allow fluid flow from the pump **136**. When fluid flows to the heat exchanger **23** heat generated by battery **22** is drawn into the atmosphere by the refrigerant passing therethrough. Fluid from the heat exchanger **23** is communicated through a pump **170** and into a housing **172** of the battery **22** where the fluid absorbs heat and returns to heat changer **23** through fluid line **142**. When the refrigerant absorbs heat generated by battery **22**, at least a portion of the refrigerant may undergo phase change to gas. The mixture of gaseous/liquid refrigerant exits the housing **172** of battery **22** through battery coolant outlet line **142** that is connected to separator **144**. The temperature of the battery **22** as indicated by a temperature sensor **174** may be monitored by a controller as described later.

[0036] Separator **144** includes a reservoir **146** that is configured to collect the liquid refrigerant received from battery coolant outlet line **142** through the heat exchanger **23** (and also from mass flow metering device **134**) and return the liquid refrigerant back to pump **136** where the liquid refrigerant can again be used to cool battery **22**. Meanwhile, the gaseous refrigerant contained within separator **144** may be released from separator **144** through a pressure regulation valve **150** located atop separator **144**. After exiting pressure regulation valve **150**, the gaseous refrigerant enters a second battery separator outlet line **152** that is connected to suction line **44** of compressor **40**.

[0037] According to the above-described configuration of coolant system **28**, the refrigerant that is typically used for controlling a temperature of a cabin of the vehicle **10** can also be used to simultaneously cool a drive assembly **94***a*, **94***b* of the vehicle **10** that includes an electric drive motor **12***a*, **12***b* and associated power electronics module **14***a*, **14***b* that includes a power inverter device. The refrigerant that is typically used for controlling the temperature of the cabin of the vehicle can also be used to cool a battery assembly **22** of the vehicle **10**. Accordingly, a separate cooling system that requires a chiller to cool the drive assemblies **94***a*, **94***b* and/or battery **22** can be omitted.

[0038] The compressor **40** has a hot gas cycle loop **80** that is in fluid communication with the discharge line **50** through a tee joint **82**. An expansion device with shutoff **84** receives hot refrigerant in the gas state which is communicated to a separator **86**. The separator **86** also receives refrigerant from the loop **32**, **34**, **36** and **38**.

[0039] The switching valve **140** receives refrigerant from the discharge line **50** through a tee joint **87** and a switching valve inlet line **88**.

[0040] Referring now to FIGS. **2** and **3**, cooling system **28** may include a controller **154** for controlling operation of various features of the cooling system **28** such as compressor **40**, switching valve **140**, mass flow devices **100***a*, **100***b*, **134**, pumps **104***a*, **104***b* and **136**, valve **63**,**66** of cabin loop **32**, switching valves **63**, **66**, drive assemblies **94***a*, **94***b*, and battery **22**. The controller **154** also forms a refrigerant monitoring system to monitor the quality of refrigerant and prevent damage to the compressor. To simplify the figures the electrical connections are not illustrated in FIG. **2**. Also not shown in FIG. **2**, pumps **104***a*, **104***b*, and **136** may also be controlled by controller **154**. Controller **154** may be an electronic control unit (ECU) of vehicle **10** having a non-transitory memory programmed to control the various functions of the system. The controller **154** may be separate from the ECU. Although not illustrated, it should be understood that controller **154** may also be used to operate various features of sub-loops **34**, **36**, and **38**.

[0041] It should be understood that separators **120***a*, **120***b*, and **144** each include a fill or liquid level sensor **160** and pressure/temperature sensor **162**. While only a single sensor **162** is illustrated for monitoring pressure and temperature, it should be understood that separators **120***a*, **120***b*, and **144** may include an individual sensor for monitoring pressure and an individual sensor for monitoring temperature. That is, the single sensor **162** illustrated in FIG. **3** for monitoring pressure/temperature is shown for simplicity of illustration.

[0042] The sub-loops **34**, **36**, and **38** are designed for cooling drive assemblies **94***a*, **94***b* (sometimes referred to as an Electric Drive Module or EDM) and battery **22** using refrigerant in two phases; a liquid phase of the refrigerant and a gas phase of the refrigerant. As noted above, the refrigerant used to cool drive assemblies **94***a*, **94***b* and battery **22**, as it exchanges heat with these devices, will undergo phase change from liquid to gas. Once the two-phase mixture of refrigerant reaches separators **120***a*, **120***b*, and **144**, the liquid refrigerant will settle in reservoirs **124***a*, **124***b*, and **146**. The amount of liquid refrigerant contained in reservoirs **124***a*, **124***b*, and **146** may be monitored by liquid level sensors **160**, and a signal indicative of the amount of refrigerant contained in reservoirs **124***a*, **124***b*, and **146** can be communicated to the controller **154**.

[0043] Separators **120***a*, **120***b*, and **144** will also collect refrigerant in the gaseous phase. A temperature/pressure of the gaseous refrigerant contained in separators **120***a*, **120***b*, and **144** may be monitored by pressure/temperate sensor **162**, and signal(s) indicative of the pressure and temperature of the gaseous refrigerant can be communicated to the respective controller **154**.

[0044] The gaseous refrigerant contained in separators **120***a*, **120***b*, and **144** can be released from separators **120***a*, **120***b*, and **144** by operation of pressure regulation valves **128***a*, **128***b*, and **150**. After exiting separators **120***a*, **120***b*, and **144**, the gaseous refrigerant will subsequently be routed to suction line **44** for compression by compressor **40** before being directed to condenser **18**, which condenses and cools the refrigerant. After exiting condenser **18**, the now subcooled liquid refrigerant can then travel to each of the sub-loops **34**, **36**, and **38** by being drawn by pumps **104***a*, **104***b*, and **136**, respectively.

[0045] According to the present disclosure, coolant system **28** is designed to control the amount of liquid refrigerant that is permitted to travel to sub-loops **34**, **36**, and **38** based on an amount of gaseous refrigerant that is released from separators **120***a*, **120***b*, and **144** by pressure regulation valves **128***a*, **128***b*, and **150**. Put another way, the amount of liquid refrigerant that is permitted to travel back to sub-loops **34**, **36**, and **38** from condenser **18** is dictated by the amount of gaseous refrigerant that is released by pressure regulation valves **128***a*, **128***b*, and **150**.

[0046] In an unmetered loop, by conservation of mass, the total amount of liquid refrigerant permitted to reenter the sub-loops **34**, **36**, and **38** from condenser **18** will be equal to the amount of gaseous refrigerant that is released by pressure regulation valves **128***a*, **128***b*, and **150** and returned to sub-loop **32** (cabin-refrigeration loop). It should be understood, however, that use of an unmetered loop would result in the sub-loops **34**, **36**, and **38** being full of only liquid refrigerant, which would not permit the sub-loops **34**, **36**, and **38** from benefitting from the refrigerant undergoing phase change to gas when cooling drive assemblies **94***a*, **94***b*, and battery **22**. Accordingly, metering the amount of gaseous refrigerant that is permitted to exit separators **120***a*, **120***b*, and **144** by pressure regulation valves **128***a*, **128***b*, and **150** and metering the amount of liquid that can enter separators **120***a*, **120***b*, and **144** using mass flow metering devices **100***a*, **100***b*, and **134** can be used to slow the amount of liquid refrigerant flowing back to sub-loops **34**, **36**, and **38** from condenser **18** to more effectively utilize the refrigerant of cooling system **28** to cool drive assemblies **94***a*, **94***b*, and battery **22**.

[0047] Controller **154** based on signals indicative of the amount of liquid contained in separators **120***a*, **120***b*, and **144** received from liquid level sensors **160**, and signals indicative of pressure and temperature received from pressure/temperature sensors **162**, may control pressure regulation valves **128***a*, **128***b*, and **150** and mass flow metering devices **100***a*, **100***b*, and **134** to dynamically control the amount of cooling provided to drive assemblies **94***a*, **94***b*, and battery **22**, as needed.

[0048] While cooling of battery **22** is substantially similar to that of drive assemblies **94***a*, **94***b*, it should be understood that it is preferable that the pressure of the refrigerant at an inlet of pump **136** is controlled to be less in comparison to that of sub-loops **34** and **36** so that the temperature in sub-loop **38** having battery **22** will be low enough to allow for proper heat transfer away from battery **22**.
[0049] Moreover, it should be understood that the pressure of the gaseous refrigerant exiting separators **120***a*, **120***b*, and **144** may be strictly controlled by pressure regulation valves **128***a*, **128***b*, and **150** to match a suction pressure located in suction line **44**, which may be necessary for cabin heat exchanger **56** to operate properly (e.g., to permit sub-loop **32** to properly heat/cool a cabin **17** of the vehicle **10**). Further, by matching the suction pressure in suction line **44**, overall function of system **28** is ensured because proper directional flow of the refrigerant to the compressor **40** is maintained (i.e., the refrigerant will be unable to flow backwards in system **28**) so that the gaseous refrigerant received from separators **120***a*, **120***b*, and **144** can be compressed by compressor **40** and then condensed by condenser **18**.
[0050] The controller **154** may be in communication with a vehicle plug monitor circuit **310**. The vehicle plug monitor circuit **310** may be disposed with the controller **154** or may be external circuit. The vehicle plug monitor circuit **310** generates a plug monitor signal that indicates the vehicle is plugged into a power source. The controller **154** may act in response to the plug monitor signal. If the vehicle plug monitor circuit **310** is disposed within the controller **154**, the controller area network **312** may communicate the vehicle plug signal to the controller **154**. Mechanical switching devices may sense to coupling of a plug to the vehicle. An electrical switching device may sense a charging voltage being coupled to the vehicle. As mentioned above, the compressor **40** consumes a lot of energy to form liquid refrigerant and therefore is desirable to operate the compressor **40** while the vehicle plug monitor circuit **310** indicates the vehicle **10** is plugged into an external power source **314**. The energy from the external power source may operate the compressor directly or the compressor may be powered from the vehicle battery that is being charged.
[0051] The controller **154** also has a comparison circuit **316**. The comparison circuit **316** may compare the fill levels from the fill level sensors **160** located at the various separators **120***a*, **120***b* and **144** to a fill level threshold. The system may act to fill the separators **120***a*, **120***b* and **144** with liquid in an uncontrolled manner or in a controlled manner. That is, the system may be used to prioritize the loop **34**, **36** or **38** that receives the liquid refrigerant when controlled. For example, pre-loading liquid refrigerant in the separator **144** in loop **38** may be desirable since the battery **22** typically requires more cooling than other components. Pre-loading liquid refrigerant in the separator **144** is therefore desirable. In one example, the mass flow device **134** associated with loop **38** may be opened before the mass flow devices **100***a*, **100***b* of loop **34** and **36**, respectively.
[0052] The comparison circuit **316** may be used to compare the temperature at the separator to a temperature threshold or the pressure at the pressure threshold to a pressure threshold. Either or both comparisons may be used to determine whether filling the separator with liquid refrigerant is to be initiated.
[0053] The controller **154** may also be in communication with an ambient temperature sensor **320** that generates an ambient temperature signal corresponding to a vehicle temperature of or around the vehicle. The ambient temperature sensor **320** may be directly coupled to the controller **154**. However, the ambient temperature may also be communicated through the controller area network **312**. The comparison circuit **316** may also compare the ambient temperature to an ambient temperature threshold. That is, the ambient temperature may be used to determine whether or not cooling is desired and therefore whether or not pre-loading of liquid refrigerant is desired.
[0054] In FIG. **2**, a quality refrigerant sensor **200** is disposed within the suction line **44** and acts as an inlet. The refrigerant quality sensor **200** is an optical sensor that is used to determine the quality of the refrigerant within the suction line **44** that leads to the inlet **46** of the compressor **40**. The

refrigerant quality sensor **200** generates an electrical signal corresponding to an amount or percentage of liquid within the refrigerant. As mentioned above, preventing liquid from entering the compressor **40** prevents damage to the compressor during operation of the system.

[0055] One way to use the optical sensor **200** is for controlling the pumps **104***a*, **104***b* and the mass flow metering devices **100***a*, **100***b* and **134**. As will be described in greater detail below relative to FIG. **5**, a sensed quality estimate for the refrigerant may be compared to a target quality (based on heat load) and the pumps **104***a*, **104***b* and the mass flow metering devices **100***a*, **100***b* and **134** may be controlled to change the refrigerant flow through the thermal circuit or sub-circuit. That is, when there is a difference between the sensed quality and the estimated quality, the flow of refrigerant may be restricted or increased. For example, if the quality is high, the pump speed may be increased and optionally the mass flow metering device may be opened for a particular loop. If the quality is low, the pump speed may be reduced and, optionally the mass flow metering device may be closed to reduce the mass flow into that subloop. The purpose of knowing the quality of the refrigerant coming out of the heat source is to be able to maintain a balance of mass of refrigerant within the system.

[0056] Another way to use the sensor **200** is for activating a compressor deactivation circuit **324**. The compressor deactivation circuit **324** is disposed in the controller **154**. The compressor deactivation circuit **324** receives the electrical signal from the refrigerant quality sensor **200**. The electrical signal from the refrigerant quality sensor **200** corresponds to a quality signal. The quality corresponds to an amount of liquid and or gas (vapor) refrigerant within the refrigerant within the quality sensor **200**. The compressor deactivation circuit **324** performs a comparison of the quality with a quality threshold. When the amount of liquid is greater than a liquid quality threshold, the compressor deactivation circuit **324** deactivates the compressor **40** by generating a disable signal. Deactivation may take place using a relay or switch **326** that disconnects the compressor **40** from the power source. Of course, the compressor **40** may be electrically controlled and a disable signal may be provided directly to the compressor **40** and the control circuitry therein to stop the compressor from rotating and prevent damage thereto. The threshold may be set depending on the characteristics of the compressor. For example, when the amount of liquid is above 5%, the compressor **40** is disabled and prevented from rotating.

[0057] Referring now to FIGS. **4**A-**4**C, details of the optical refrigerant quality sensor **200** are set forth. The refrigerant quality sensor **200** includes an elongated housing **410**. The elongated housing **410** in this example is cylindrical and has a first end wall **412**, a second end wall **414** and at least one sidewall **416** extending between the first end wall **412** and the second end wall **414**. When the elongated housing **410** is cylindrical, one cylindrical wall **416** is provided. However, other shapes including three or more side walls may be provided.

[0058] The first end wall **412** may be completely or partially formed of a transparent material. The transparent material allows light from a light source **420** to enter the elongated sensor housing **410**. The light source **420** has light directed through the elongated sensor housing **410** in a longitudinal direction indicated by the longitudinal axis **411**. The light source **420** may be a light emitting diode, a laser, an OLED or a conventional bulb.

[0059] The light from the light source **420** traverses the elongated housing **410** and is received at a photosensor **422**. The photosensor **422** may be one of variety of technologies including a charge coupled device (CCD) or a complimentary metal-oxide semiconductor (CMOS) device. Of course, other types of photosensors may be used. Multiple photosensors may be used and may be capable of resolving the frequency, location, and dispersal of a laser beam or beams landing thereon. The photosensor **422** generates an output signal that corresponds to the quality of the refrigerant within the elongated housing **410**. The quality may correspond to the phase distribution of the refrigerant in the elongated housing. The phase distribution corresponds to the amount of liquid vapor refrigerant within the housing. The electrical signal from the photosensor **422** may correspond to the amount of liquid going to the compressor **40** as mentioned above.

[0060] The end wall **412** may also be entirely or partially transparent or may have a portion adjacent to the light source **420** that is transparent. That is, the end wall **412** may be entirely transparent or may have a transparent window. The portion of the end wall **414** that aligns with the photosensor **422** is also transparent.

[0061] The sidewall **416** has a refrigerant inlet **430** that is in fluid communication with the suction line **44**. The sidewall **416** has a refrigerant outlet **432** that is in communication with the inlet **46** of the compressor **40**. The direction of the refrigerant is illustrated by the arrow **434**. However, the position of the light source **420** and the photosensor **422** may be reversed. That is, in this example, the refrigerant inlet **430** is closest to the light source **420** while the refrigerant outlet **432** is closest to the photosensor **422**. However, the position of the photosensor **422** and the light source **420** may be reversed. The refrigerant may be dyed a specific color to enhance the optical contrast when the light source **420** illuminates within the elongated housing **410** and the refrigerant therein. The dyed refrigerant may allow the photosensor **422** to provide higher accuracy. As mentioned above, the cross-sectional shape of the elongated housing **410** may be various shapes and therefore the refrigerant inlet **430** and the refrigerant outlet may be disposed on different sides of the cross-sectional shape.

[0062] Referring now to FIG. **5**, a method for operating the system is set forth. In step **510**, light is generated at the light source. As mentioned above, various types of wavelengths of light may be used depending upon the characteristics of the refrigerant. The wavelength may also be changed to correspond to the characteristics of the refrigerant.

[0063] In step **512**, the refrigerant is communicated into a sensor housing. In step **514**, the light is communicated through the refrigerant in the elongated sensor housing. In step **516**, light is received at a photodetector. As the light traverses the elongated housing, the light is changed so that it is received at the photodetector to indicate quality. That is, the measure optical characteristic such as transmittance varies as the amount of liquid varies. In step **518**, an electrical signal corresponding to the quality of the refrigerant is generated at the photodetector. The voltage level or a digital signal may be generated to correspond to the quality. The quality is an indicator of the amount of liquid within the refrigerant or phase distribution. That is, it is undesirable to provide liquid to the compressor. However, some small tolerable amount of liquid may be communicated to the compressor. The electrical signal may correspond to the percentage of liquid (or vapor) within the sensor housing.

[0064] In step **520**, an estimated value of how much vapor should be produced by the heat load (i.e., battery or EDM) is determined as a reference value to check the sensed quality against. In step **522** the difference between the estimated value and the sensed value from the sensor **200**. When there is a difference in step **522**, step **524** drives the movement of the actuator such as a mass flow metering devices and the pumps. For example, if the quality is high, the pump speed may be increased and optionally the mass flow metering device may be opened for a particular loop. If the quality is low, the pump speed may be reduced and, optionally the mass flow metering device may be closed to reduce the mass flow into that subloop. The purpose of knowing the quality of the refrigerant coming out of the heat source is to be able to maintain a balance of mass of refrigerant within the system. In this manner, by proxy, where the refrigerant is within the system is monitored so that the actuators that move the refrigerant may be adjusted to rebalance where all of the mass is to achieve a desired cooling or heating effect.

[0065] In step **522**, when there is no difference (or within a tight tolerance), the system has very little of no liquid with the vapor refrigerant. Step **528** does not change the operation of the actuators. After Step **528**, step **530** allows the compressor to operate and compress the vapor to form liquid which is communicated to separators in coolant loops or sub-loops through the condenser. Thereafter, step **510** continues to monitor the refrigerant within the sensor housing in step **510**.

[0066] The foregoing description of the embodiments has been provided for purposes of illustration and description. It is not intended to be exhaustive or to limit the disclosure. Individual elements or features of a particular embodiment are generally not limited to that particular embodiment, but, where applicable, are interchangeable and can be used in a selected embodiment, even if not specifically shown or described. The same may also be varied in many ways. Such variations are not to be regarded as a departure from the disclosure, and all such modifications are intended to be included within the scope of the disclosure.

Claims

1. A refrigerant quality sensor comprising: an elongated sensor housing comprising a first end wall and a second end wall and at least one side wall extending between the first end wall and the second end wall; a refrigerant inlet disposed in the at least one side wall; a refrigerant outlet disposed in the at least one side wall; a light source disposed at the first end wall; and a photosensor disposed at the second end wall, said photosensor generating a sensed quality signal corresponding to a quality of refrigerant within the elongated sensor housing.
2. The refrigerant quality sensor of claim 1 wherein the elongated sensor housing is cylindrical and the at least one side wall is a cylindrical wall.
3. The refrigerant quality sensor of claim 2 wherein the inlet is disposed in the cylindrical wall.
4. The refrigerant quality sensor of claim 2 wherein the outlet is disposed in the cylindrical wall.
5. The refrigerant quality sensor of claim 1 wherein the first end wall comprises a first transparent window and the second end wall comprises a second transparent window.
6. The refrigerant quality sensor of claim 1 wherein the photosensor comprises a charge coupled device or a CMOS device.
7. The refrigerant quality sensor of claim 1 wherein the light source comprises a light emitting diode or laser.
8. The refrigerant quality sensor of claim 1 wherein the electrical signal corresponds to an amount of liquid or phase distribution within the elongated housing.
9. The refrigerant quality sensor of claim 1 wherein the refrigerant is dyed refrigerant.
10. A cooling system comprising: a compressor having an inlet; the refrigerant quality sensor of claim 1; and a controller coupled to the compressor, said controller determining a target quality based on a heat load, generating an actuator control signal based on a difference between a sensed quality signal and the target quality.
11. The cooling system of claim 10 further comprising a coolant loop including the refrigerant, the compressor, and a condenser, the coolant loop receiving the refrigerant from the condenser based on the quality associated with the electrical signal.
12. The cooling system of claim 11 wherein the coolant loop comprises a separator, receives liquid refrigerant and communicates vapor refrigerant to the compressor.
13. The cooling system of claim 12 wherein the coolant loop comprising a plurality of sub-loops, wherein the separator comprises a plurality of separators, a respective separator of the plurality of separators associated with the each of the plurality of sub-loops.
14. A method of operating a cooling system comprising: communicating refrigerant into an elongated sensor housing; directing light from a light source through the refrigerant in the elongated sensor housing; generating a sensed quality signal at a photodetector corresponding to a quality of the refrigerant within the elongated sensor housing; determining a target quality based on a heat load; generating an actuator control signal based on a difference between a sensed quality signal and the target quality.
15. The method of claim 14 wherein generating an actuator control signal comprises increasing a speed of a pump when the difference indicates high quality and decreasing the speed of the pump when the difference indicates low quality.
16. The method of claim 14 wherein directing light comprises directing light from a light emitting

diode or a laser through a transparent window in an end of the elongated sensor housing.

17. The method of claim 14 wherein the quality signal corresponds to an amount of liquid, vapor or phase distribution within the elongated sensor housing.

18. The method of claim 14 further comprising communicating liquid from the compressor to a coolant loop based when the quality signal is above a quality threshold.

19. The method of claim 18 further comprising communicating liquid from the compressor to a separator within the coolant loop based on the quality signal.

20. The method of claim 19 wherein the separator comprises a plurality of separators, wherein operating the compressor comprises operating the compressor to communicate liquid refrigerant to a respective separator of the plurality of separators associated with the each of a plurality of sub-loops.