US 20160061497A1

(19) **United States**
(12) **Patent Application Publication**
CHOWDHURY et al.
(10) **Pub. No.: US 2016/0061497 A1**
(43) **Pub. Date: Mar. 3, 2016**

(54) **TWO-PASS EVAPORATOR**

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(21) Appl. No.: **14/469,000**

(22) Filed: **Aug. 26, 2014**

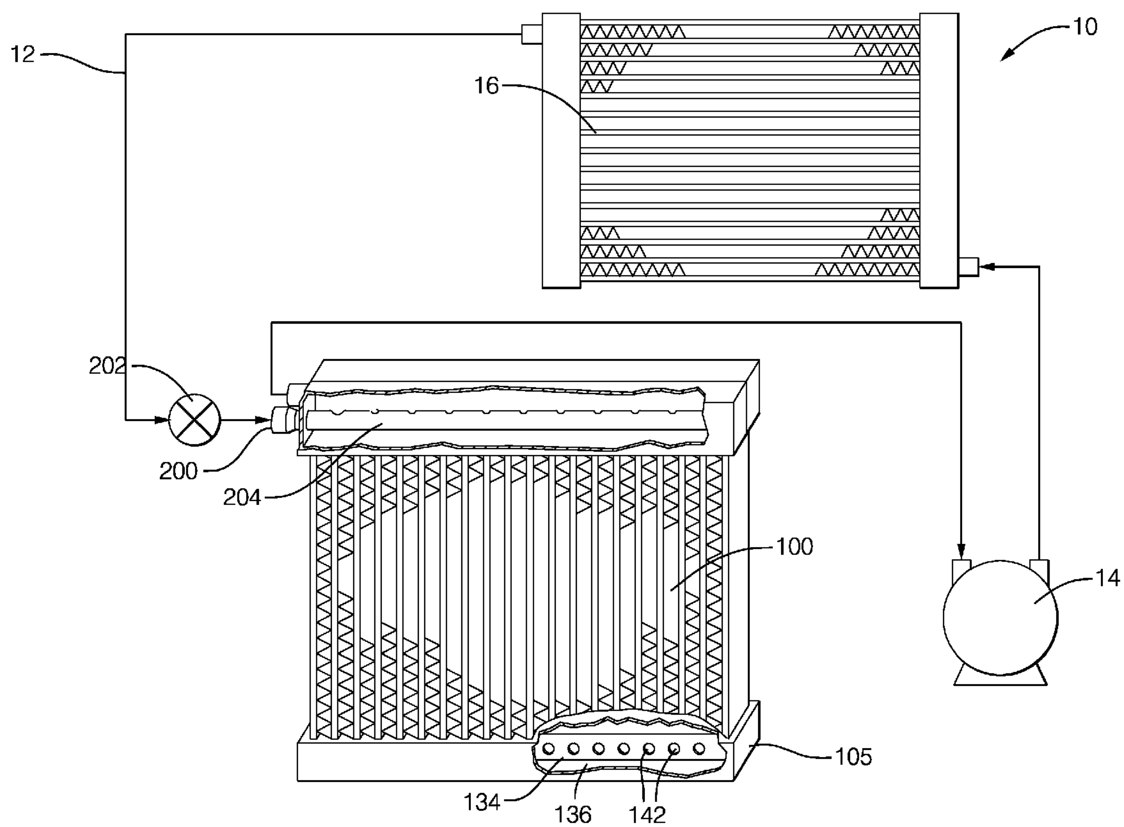
Publication Classification

(51) **Int. Cl.**
F25B 39/00 (2006.01)

(52) **U.S. Cl.**
CPC *F25B 39/00* (2013.01); *F25B 39/02* (2013.01)

(57) **ABSTRACT**

A two-pass evaporator suitable for use in an automobile includes various pressure drop devices to aliquot refrigerant into tubes that make up the two-pass evaporator. The two-pass evaporator includes a first pressure-drop device configured to receive and expand a liquid phase refrigerant into a first mixture of two-phase refrigerant; and a second pressure-drop device configured to receive and expand the first mixture of two-phase refrigerant into a second mixture of two-phase refrigerant and aliquot the second mixture of two-phase refrigerant to the first end of the first plurality of tubes. The two-pass evaporator includes a transition manifold that may house a flow-modulation plate disposed therein and configured to segregate the transition manifold into an upstream portion and a downstream portion. The flow-modulation device works in conjunction with the upstream pressure drop devices to aliquot refrigerant from the first plurality of tubes to the second plurality of tubes.



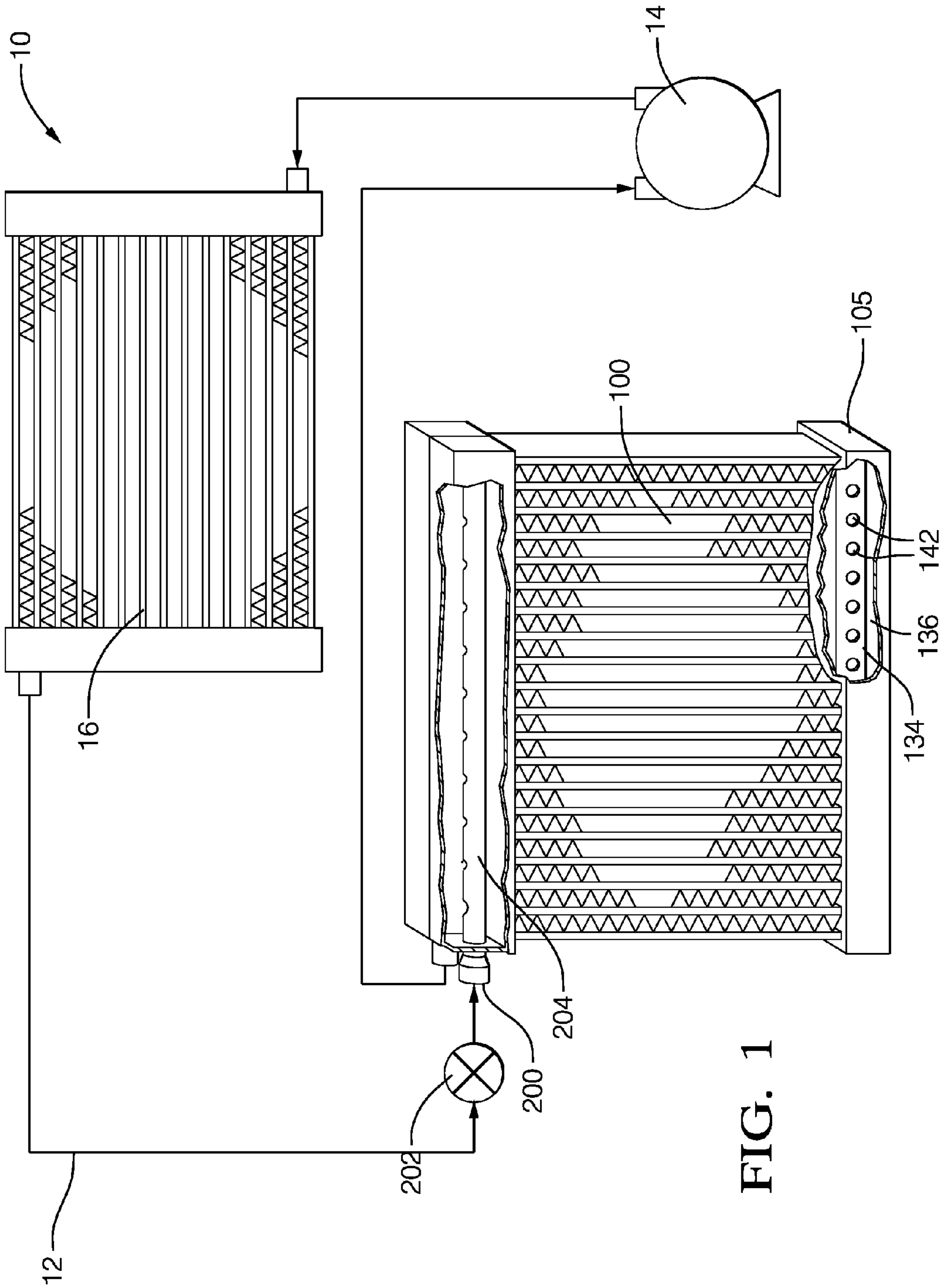


FIG. 1

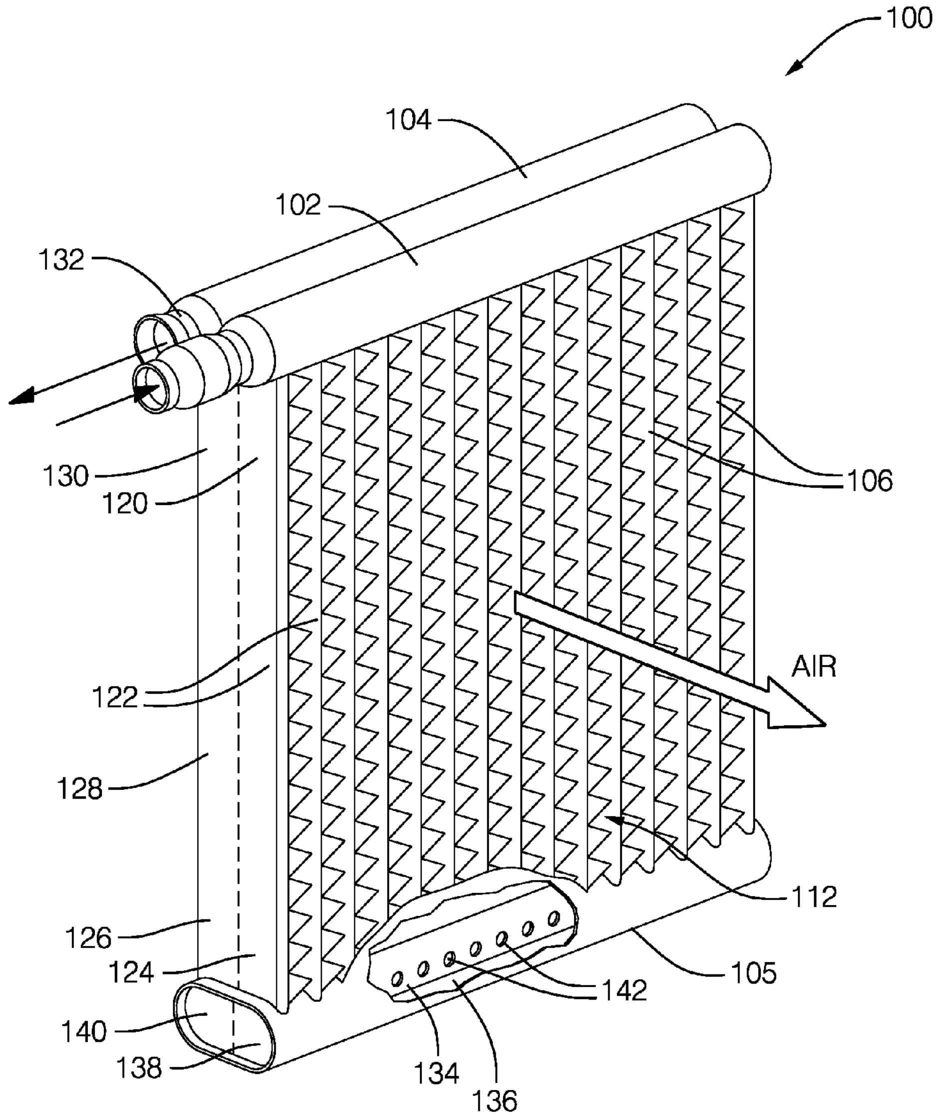

100
104
102
132
106
130
120
AIR
122
128
112
126
124
105
142
140
138
134
136

FIG. 2

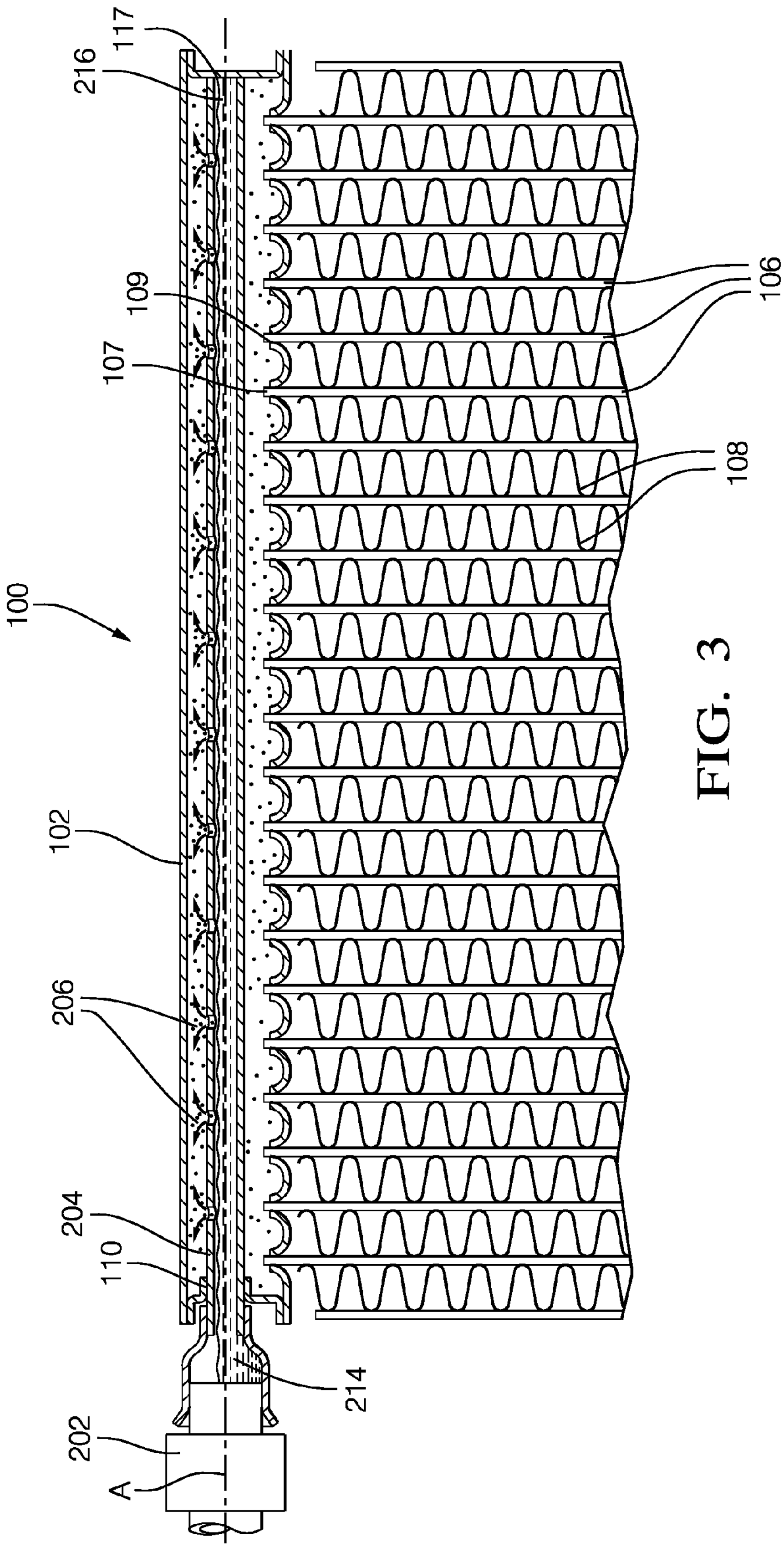


FIG. 3

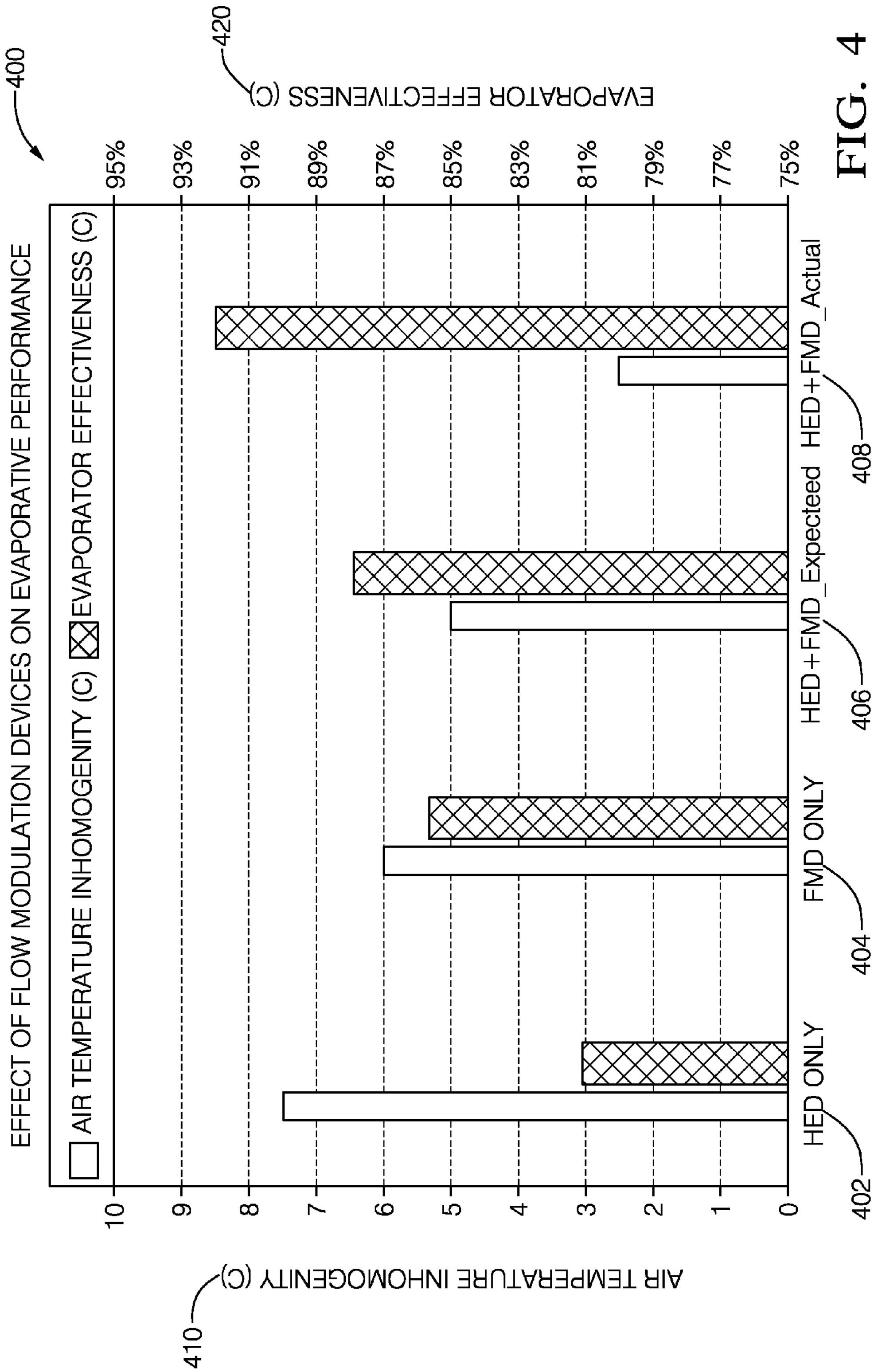

400
EFFECT OF FLOW MODULATION DEVICES ON EVAPORATIVE PERFORMANCE
AIR TEMPERATURE INHOMOGENITY (C)
EVAPORATOR EFFECTIVENESS (C)
10
9
8
7
6
5
4
3
2
1
0
95%
93%
91%
89%
87%
85%
83%
81%
79%
77%
75%
HED ONLY
FMD ONLY
HED+FMD_Expecteed
HED+FMD_Actual
402
404
406
408
AIR TEMPERATURE INHOMOGENITY (C)
410
EVAPORATOR EFFECTIVENESS (C)
420

FIG. 4

TWO-PASS EVAPORATOR

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is a continuation-in-part application that claims the benefit under 35 U.S.C. §120 of U.S. patent application Ser. No. 14/069,878 filed Nov. 1, 2013, the entire disclosure of which is hereby incorporated herein by reference.

TECHNICAL FIELD OF INVENTION

[0002] This disclosure generally relates to a two-pass evaporator, and more particularly relates to features within the two-pass evaporator that aliquot refrigerant across the tubes that are part of the two-pass evaporator.

BACKGROUND OF INVENTION

[0003] An air-conditioning system for a motor vehicle typically includes a refrigerant loop having an evaporator located within a heating, ventilation, and air-conditioning (HVAC) module for supplying conditioned air to the passenger compartment, an expansion device located upstream of the evaporator, a condenser located upstream of the expansion device in front of the engine compartment, and a compressor located within the engine compartment upstream of the condenser. The above mentioned components are hydraulically connected in series within the closed refrigerant loop.

[0004] The compressor compresses and circulates a refrigerant through the closed refrigerant loop. Starting from the inlet of the evaporator, a low pressure two-phase refrigerant having mixture of liquid and vapor enters the evaporator and flows through the tubes of the evaporator where it expands into a low pressure vapor refrigerant by absorbing heat from an incoming air stream. The low pressure vapor refrigerant then exits the outlet of the evaporator and enters the compressor where it is compressed into a high pressure high temperature vapor. The high pressure vapor refrigerant then flows through the condenser where it condenses into a high pressure liquid refrigerant by releasing the heat to the ambient air outside the motor vehicle. The condensed high pressure liquid refrigerant is returned to the evaporator through the expansion device, which expands the high pressure liquid refrigerant to a low pressure, low temperature mixture of liquid-vapor refrigerant to repeat the cycle.

[0005] A conventional multi-pass evaporator includes an inlet manifold, an outlet manifold, and a plurality of tubes hydraulically connecting the manifolds. Additionally, there may be one or more intermediate or transition manifolds, that interconnect groups of tubes between the inlet and outlet manifold. It is desirable to aliquot, that is distribute into as equal parts as much as possible, two-phase refrigerant to the tubes of the evaporator to provide uniform cooling of the airstream. If two-phase refrigerant enters the inlet manifold at a relatively high velocity, the liquid phase of the refrigerant is carried by momentum of the flow further away from the entrance of the inlet manifold to the distal end of the inlet manifold. For relatively high velocity, the tubes closest to the inlet manifold entrance may receive predominantly the vapor phase and the tubes near the distal end of the inlet manifold receive predominantly the liquid phase. On the other hand, if the two-phase refrigerant enters the inlet manifold at a relatively low velocity, the tubes closest to the inlet manifold entrance may receive predominantly the liquid phase and the tubes near the distal end of the inlet manifold may receive predominantly the vapor phase. In either case, this results in the undesirable misaliquoting of the refrigerant flowing through the tubes.

SUMMARY OF THE INVENTION

[0006] In accordance with one embodiment, a two-pass evaporator suitable for use in an automobile is provided. The two-pass evaporator includes an inlet manifold, a transitional manifold, an outlet manifold, a first pressure drop device, and a second pressure drop device. The inlet manifold is configured to define a chamber for containing refrigerant, define an inlet port for receiving refrigerant into the chamber, and hydraulically couple the inlet port to a first end of a first plurality of tubes. The transition manifold is configured to hydraulically couple a second end of the first plurality of tubes to a first end of a second plurality of tubes arranged parallel to the first plurality of tubes. The outlet manifold is located proximate to the inlet manifold. The outlet manifold is configured to define an outlet port and hydraulically couple a second end of the second plurality of tubes to the outlet port. The first pressure-drop device is located proximate to the inlet port. The first pressure-drop device is configured to receive and expand a liquid phase refrigerant into a first mixture of two-phase refrigerant. The second pressure-drop device located within the inlet manifold. The second pressure-drop device is configured to receive and expand the first mixture of two-phase refrigerant into a second mixture of two-phase refrigerant and aliquot the second mixture of two-phase refrigerant to the first end of the first plurality of tubes. The first pressure-drop device and the second pres sure-drop device cooperate to form a hybrid expansion device.

[0007] In another embodiment, the transition manifold includes a flow-modulation plate disposed therein and configured to segregate the transition manifold into an upstream portion and a downstream portion, and aliquot refrigerant from the first plurality of tubes to the second plurality of tubes.

[0008] In yet another embodiment, the flow-modulation plate defines a plurality of openings configured to aliquot refrigerant from the first plurality of tubes to the second plurality of tubes.

[0009] Further features and advantages will appear more clearly on a reading of the following detailed description of the preferred embodiment, which is given by way of non-limiting example only and with reference to the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

[0010] The present invention will now be described, by way of example with reference to the accompanying drawings, in which:

[0011] FIG. **1** shows a schematic of an air conditioning system with an evaporator having a hybrid expansion device;

[0012] FIG. **2** shows an exemplary two-pass evaporator having a hybrid expansion device;

[0013] FIG. **3** shows a cross-sectional view of the inlet manifold of the evaporator shown in FIG. **2**; and

[0014] FIG. **4** shows a graph of data related to the evaporator of FIG. **1**.

DETAILED DESCRIPTION

[0015] FIG. **1** is a non-limiting example of an air conditioning system **10** having a closed refrigerant loop **12** hydraulically connecting a compressor **14**, a condenser **16**, and a two-pass evaporator **100** in series. The two-pass evaporator **100** includes a hybrid expansion device, hereafter the HED **200**, configured to provide uniform refrigerant aliquoting through the two-pass evaporator **100** for all operating refrigerant flow velocities caused by variations in the compressor **14** speed. The HED **200** includes a first pressure-drop device such as a Low-Pressure Thermostatic Expansion Valve, hereafter the LP-TXV **202**, and a second pressure-drop device such as an Enhanced Orifice Tube, hereafter the EOT **204**.

[0016] FIGS. **2** and **3** illustrate further details of the two-pass evaporator **100**. The two-pass evaporator **100** includes an inlet manifold **102**, an outlet manifold **104**, and plurality of tubes **106** hydraulically connecting the inlet manifold **102** to the outlet manifold **104** for refrigerant flow therebetween. The tubes **106** together with a transition manifold **105** to define a U-shaped path for refrigerant flow from the inlet manifold **102** to the outlet manifold **104**, thereby enabling the inlet manifold **102** and outlet manifold **104** to be placed in a side-by-side parallel arrangement. The inlet open ends **107** of the tubes **106** are inserted through slots **109** positioned along the inlet manifold **102** for refrigerant flow from the inlet manifold **102** to the tubes **106**. The inlet manifold **102** and outlet manifold **104** are shown above the tubes **106** with respect to the direction of gravity. A plurality of fins **108** is disposed between and materially joined to the tubes **106** to facilitate heat exchange between the refrigerant and a stream of ambient air. The tubes **106** and fins **108** are formed of a heat conductive material, preferably an aluminum alloy, assembled onto the inlet manifold **102**, the transition manifold **105**, and the outlet manifold **104** and brazed together to form the two-pass evaporator heat exchanger assembly.

[0017] Shown in FIG. **3** is a cross-sectional view of the inlet manifold **102** of the two-pass evaporator **100** extending along a manifold axis A. The inlet manifold **102** includes an inlet port **110** for receiving the EOT **204**, which is configured to cooperate with the LP-TXV **202** to improve refrigerant aliquoting across tubes **106** of the two-pass evaporator **100**. The LP-TXV **202** expands a liquid refrigerant from the condenser into a first mixture of two-phase refrigerant and the EOT **204** expands the first mixture into a second mixture of two-phase refrigerant.

[0018] The EOT **204** may be disposed within the chamber defined by the inlet manifold **102**, extending substantially along the length of the chamber and substantially parallel with the manifold axis A. The EOT **204** includes an inlet end **214**, a distal end **216** that may be a blind end opposite that of the inlet end **214**, and a plurality of orifices **206** therebetween. The inlet end **214** is in direct hydraulic connection with the LP-TXV **202**. The distal end **216** is typically mounted by capturing it in the end cap **117** of the inlet manifold **102**. The plurality of orifices **206** may be arranged in a linear array parallel to the manifold axis A and oriented away from the inlet open ends **107** of the tubes **106**, preferably 180 degrees from the inlet open ends **107** and substantially in the opposite direction of gravity. As shown in FIG. **2**, the in-vehicle position is such that the inlet manifold **102** and the outlet manifold **104** are at the top, the transition manifold **105** is at the bottom, and the evaporator face **112** is substantially perpendicular to the ground. In a case where the evaporator face **112** is tilted towards the ground, up to 60° from the vertical, it is still preferable that the orifices **206** of the EOT **204** are substantially opposite to the gravity direction.

[0019] The HED **200** provides a two stage pressure drop, in which the total pressure drop is apportioned between the LP-TXV **202** and the EOT **204** and is equivalent to the pressure drop of a conventional TXV. It was surprisingly found that a controlled two stage pressure drop provided by the LP-TXV and EOT working in unison, resulted in the improved aliquoting of refrigerant through the tubes **106** of the two-pass evaporator **100**. The LP-TXV **202** is configured to provide a first mixture of two-phase refrigerant to the EOT **204**. The EOT **204** serves as a retention and expansion device where it retains and accumulates the first mixture of two-phase refrigerant until the liquid part of the incoming mixture substantially fills the interior volume of the EOT **204** before being discharged through the orifices **206** as a second mixture of two-phase refrigerant, thereby aliquoting the refrigerant across the tubes **106**.

[0020] Referring again to FIGS. **1** and **2**, the two-pass evaporator **100**, which is suitable for use in an automobile, includes an inlet manifold **102**. The inlet manifold is configured to define the chamber for containing refrigerant, define the inlet port **110** for receiving refrigerant into the chamber, and hydraulically couple the inlet manifold **110** to a first end **120** of a first plurality of tubes **122**. The transition manifold **105** is configured to hydraulically couple a second end **124** of the first plurality of tubes **122** to a first end **126** of a second plurality of tubes **128** arranged parallel to the first plurality of tubes **122**. As noted above, this advantageously allows the outlet manifold **104** to be located proximate to the inlet manifold **102**. The outlet manifold defines an outlet port **132** and hydraulically couples a second end **130** of the second plurality of tubes **128** to the outlet port **132**.

[0021] The two-pass evaporator **100** includes a first pressure-drop device (LP-TXV **202**) located proximate to the inlet port **110**. The first pressure-drop device is configured to receive and expand a liquid phase refrigerant into a first mixture of two-phase refrigerant. The two-pass evaporator **100** also includes a second pressure-drop device (EOT **204**) located within the inlet manifold **102**. The second pressure-drop device is configured to receive and expand the first mixture of two-phase refrigerant into a second mixture of two-phase refrigerant and aliquot the second mixture of two-phase refrigerant to the first end **120** of the first plurality of tubes **122**. The first pressure-drop device and the second pressure-drop device cooperate to form a hybrid expansion device (HED **200**).

[0022] It was discovered that temperature uniformity across the various tubes could be improved if the transition manifold **105** was equipped with a flow-modulation plate **134**. The flow-modulation plate **134** is disposed generally within the transition manifold, and is configured to segregate a transition cavity **136** defined by the transition manifold **105** into an upstream portion **138** and a downstream portion **140**. In one embodiment, the flow-modulation plate **134** includes or defines a plurality of openings **142** configured to aliquot refrigerant from the first plurality of tubes to the second plurality of tubes.

[0023] While not subscribing to any particular theory, it is believed that the flow-modulation plate **134** provides flow restriction that better aliquots refrigerant flowing from the first plurality of tubes **122** to the second plurality of tubes **128**. The flow-modulation plate **134** creates a back pressure on the refrigerant from the first plurality of tubes **122** by restricting the flow (i.e.—choking the flow) of refrigerant as refrigerant moves from an upstream portion **138** to a downstream portion **140**. This causes better distribution of refrigerant in both the first plurality of tubes **122** to the second plurality of tubes **128**. This advantage of the flow modulation plate further enhances the aliquoting functionality of the HED **200**. If HED **200** performs its intended function by aliquoting the two-phase refrigerant into the first plurality of tubes **122**, the benefit realized by including the flow-modulation plate **134** may be less evident and the size of the opening **142** in the flow-modulation plate **134** can be larger to offer less flow restriction.

[0024] By contrast, for an HED **200** that is designed to perform within a particular flow range, if the refrigerant flow, and consequently the pressure drop across HED **200**, is outside the design range, the HED **200** may not be able to satisfactorily perform its aliquoting function. Also, for high refrigerant flows beyond the HED design range, an undesirable refrigerant hiss or whistle noise may be generated. The noise is generated by refrigerant turning from liquid to vapor as the refrigerant emanates at high velocity from the orifices **206** in the EOT **204** of the HED **200**. In general, if the HED **200** cannot deliver good flow distribution due to some design constraint such as a noise limit, then the benefit of the flow-modulation plate **134** may be more useful. In this case, the flow-modulation plate **134** may have smaller sized openings **142** and thus may offer higher flow resistance to the refrigerant, thereby compensating for what HED **200** could not achieve. The HED **200** functions cooperatively with the flow-modulation plate **134** to deliver good overall refrigerant aliquoting with minimal refrigerant noise and across a wider range of refrigerant flows. Together, the HED **200** and flow modulation plate **134** forms the hybrid flow modulation system (HFMS).

[0025] FIG. **4** is a graph **400** of test data showing performance of an evaporator comparable to the two-pass evaporator **100** described herein when equipped with only the HED **200** (HED only **402**), that is without the flow modulation plate **134** (labeled FMD in FIG. **4**); equipped with only the flow modulation plate **134** (FMD only **404**), that is without the HED **200**; the expected performance characteristics for a two-pass evaporator equipped with both the HED **200** and the flow modulation plate **134** (HED+FMD_Expected **406**); and the actual performance characteristics for the two-pass evaporator **100** equipped with both the HED **200** and the flow modulation plate **134** (HED+FMD_Actual **408**). The performance characteristics include an Air Temperature Inhomogeneity **410** and an Evaporator Effectiveness **420**. The Air Temperature Inhomogeneity **410** is determined by calculating the difference between the maximum outlet air temperature and the minimum outlet air temperature across the face of the two-pass evaporator. The Evaporator Effectiveness **420** is calculated based on a ratio of the heat transfer performance achieved by a given heat exchanger to the maximum heat transfer performance theoretically possible, which in this instance is when outlet air temperature is equal to the temperature of the refrigerant flowing through the pass through which air is coming out. The Air Temperature Inhomogeneity **410** for the HED+FMD_Expected **406** and the Evaporator Effectiveness **420** for the HED+FMD_Expected **406** are estimated based on the trend of data from tests with various evaporators with different aliquoting devices and also data from tests with different state-of-the-art evaporators used in the industry. As can be seen, the actual performance characteristics (the HED+FMD_Actual **408**) for the two-pass evaporator **100** described herein is surprisingly better than the expected result. This significant improvement is believed to be due to an unexpected synergistic interaction of the HED and FDM devices suggesting that the hybrid flow modulation system (HFMS) possess a unique ability to aliquot refrigerant in both the passes of the evaporator to maximize the performance.

[0026] Accordingly, a two-pass evaporator **100** is provided. The two-pass evaporator **100** includes several features that help to aliquot refrigerant to the tubes **106** so that the temperature across the two-pass evaporator **100** is more uniform.

[0027] While this invention has been described in terms of the preferred embodiments thereof, it is not intended to be so limited, but rather only to the extent set forth in the claims that follow.

We claim:

1. A two-pass evaporator suitable for use in an automobile, said two-pass evaporator comprising:

an inlet manifold configured to define a chamber for containing refrigerant, define an inlet port for receiving refrigerant into the chamber, and hydraulically couple the inlet port to a first end of a first plurality of tubes;

a transition manifold configured to hydraulically couple a second end of the first plurality of tubes to a first end of a second plurality of tubes;

an outlet manifold located proximate to the inlet manifold, said outlet manifold configured to define an outlet port and hydraulically couple a second end of the second plurality of tubes to the outlet port;

a first pressure-drop device located proximate to the inlet port, said first pressure-drop device configured to receive and expand a liquid phase refrigerant into a first mixture of two-phase refrigerant;

a second pressure-drop device located within the inlet manifold, said second pressure-drop device configured to receive and expand said first mixture of two-phase refrigerant into a second mixture of two-phase refrigerant and aliquot said second mixture of two-phase refrigerant to the first end of the first plurality of tubes, wherein the first pressure-drop device and the second pressure-drop device cooperate to form a hybrid expansion device.

2. The two-pass evaporator in accordance with claim **1**, wherein the transition manifold includes a flow-modulation plate disposed therein and configured to segregate the transition manifold into an upstream portion and a downstream portion, and aliquot refrigerant from the first plurality of tubes to the second plurality of tubes.

3. The two-pass evaporator in accordance with claim **2**, wherein the flow-modulation plate defines a plurality of openings configured to aliquot refrigerant from the first plurality of tubes to the second plurality of tubes.

* * * * *