



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
02.03.2016 Bulletin 2016/09

(51) Int Cl.:
F28F 9/02 (2006.01) **F28D 1/053** (2006.01)
F25B 39/02 (2006.01) **B60H 1/00** (2006.01)

(21) Application number: **15180761.7**

(22) Date of filing: **12.08.2015**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
MA

(72) Inventors:
• **Chowdhury, Sourav**
LOCKPORT, NY New York 14094 (US)
• **Kadle, Prasad S.**
WILLIAMSVILLE, NY New York 14221 (US)
• **Kowsky, Carrie M.**
LOCKPORT, NY New York 14094 (US)

(30) Priority: **26.08.2014 US 201414469000**

(74) Representative: **BRP Renaud & Partner mbB**
Rechtsanwälte Patentanwälte
Steuerberater
Königstraße 28
70173 Stuttgart (DE)

(71) Applicant: **Delphi Technologies, Inc.**
Troy, MI 48007-5052 (US)

(54) **TWO-PASS EVAPORATOR**

(57) 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.

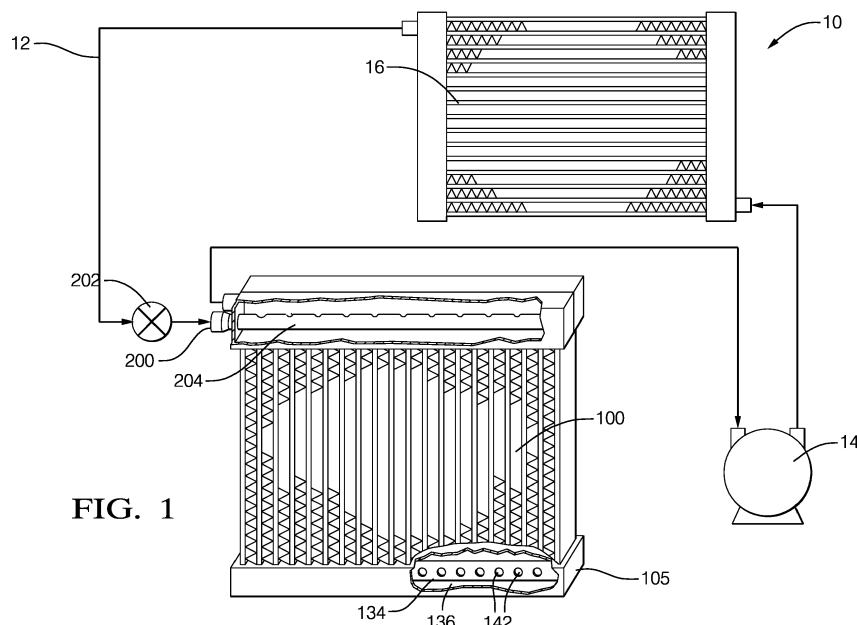


FIG. 1

Description

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 No. 14/069,878 filed November 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 pressure-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:

Fig. 1 shows a schematic of an air conditioning system with an evaporator having a hybrid expansion device;

Fig. 2 shows an exemplary two-pass evaporator having a hybrid expansion device;

Fig. 3 shows a cross-sectional view of the inlet manifold of the evaporator shown in Fig. 2; and

Fig. 4 shows a graph of data related to the evaporator of Fig. 1.

DETAILED DESCRIPTION

[0011] 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.

[0012] 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.

[0013] 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.

[0014] 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.

[0015] 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.

[0016] 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 cou-

ple 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.

[0017] 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).

[0018] 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.

[0019] 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.

[0020] 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).

[0021] 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.

[0022] 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.

5

[0023] 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.

10

Claims

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

15

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;

20

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;

25

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;

30

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.

35

40

45

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.

50

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.

55

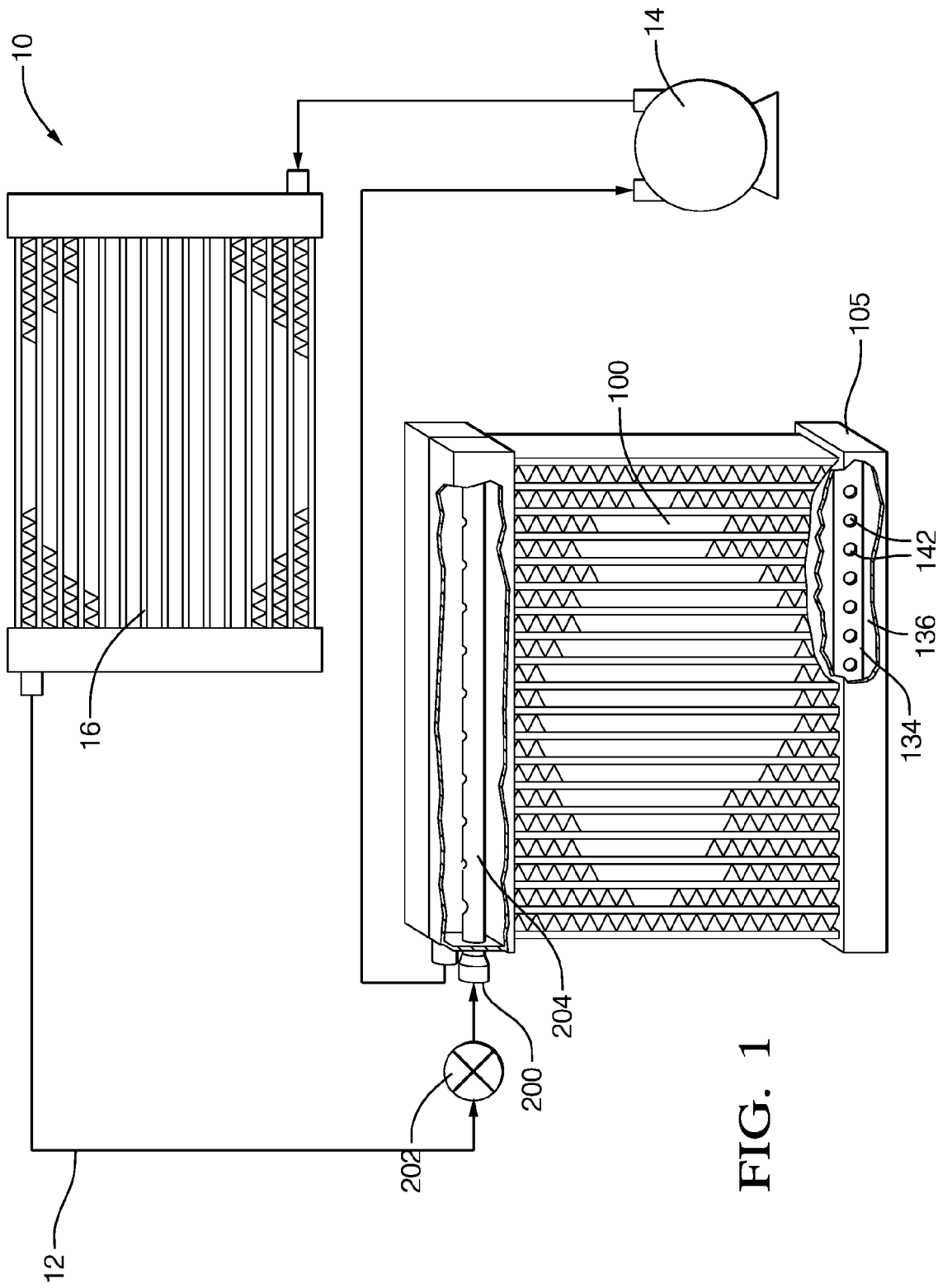


FIG. 1

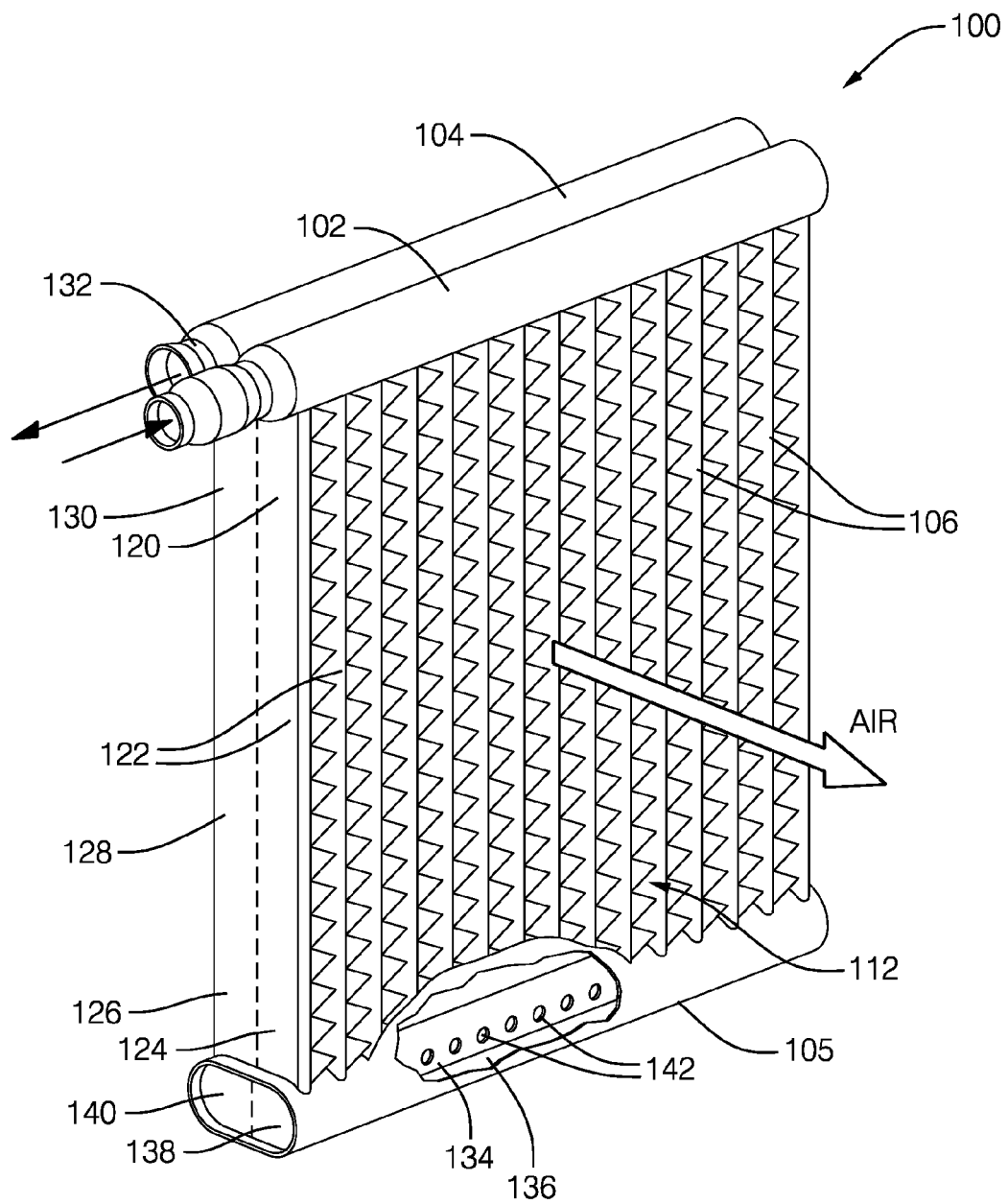


FIG. 2

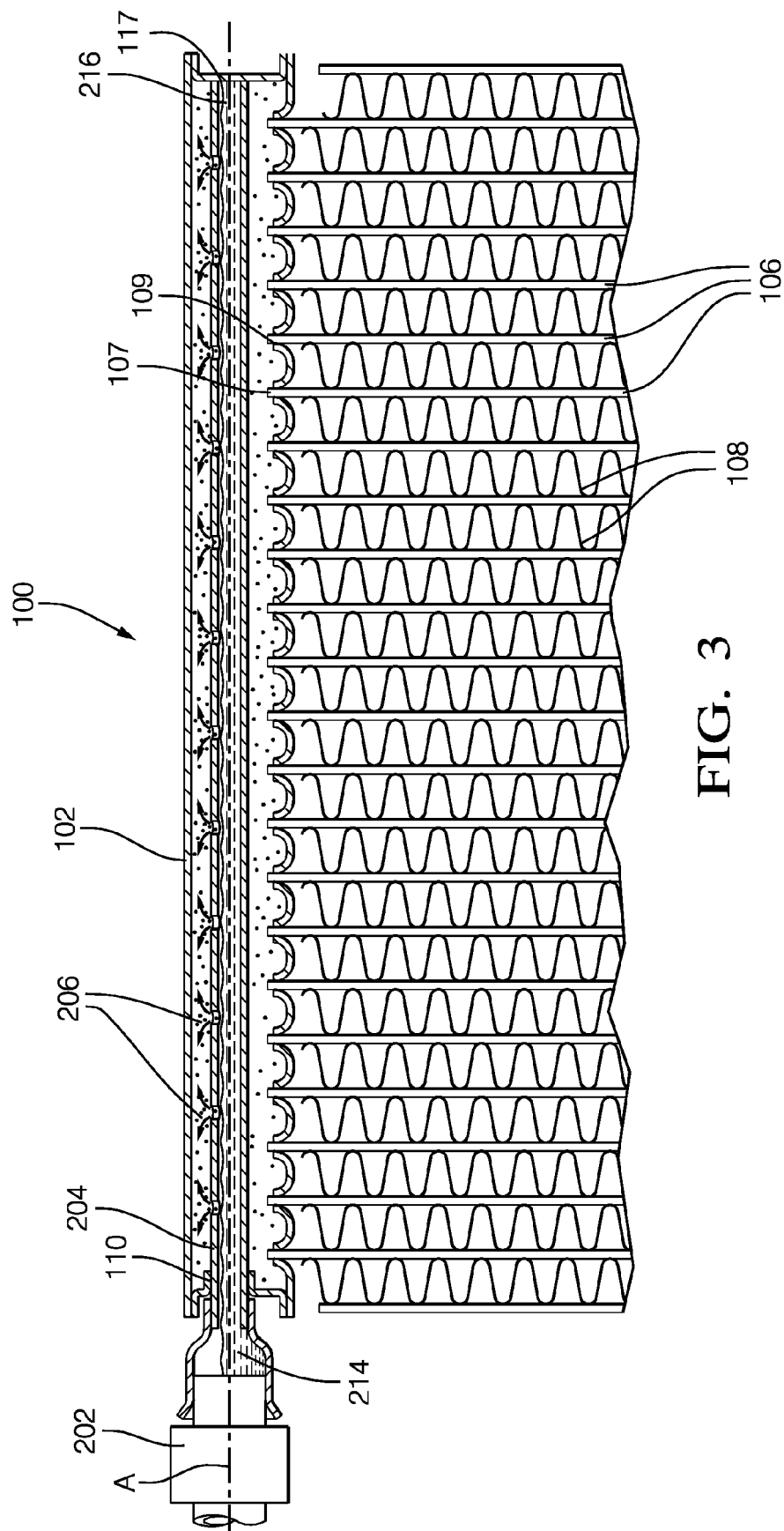


FIG. 3

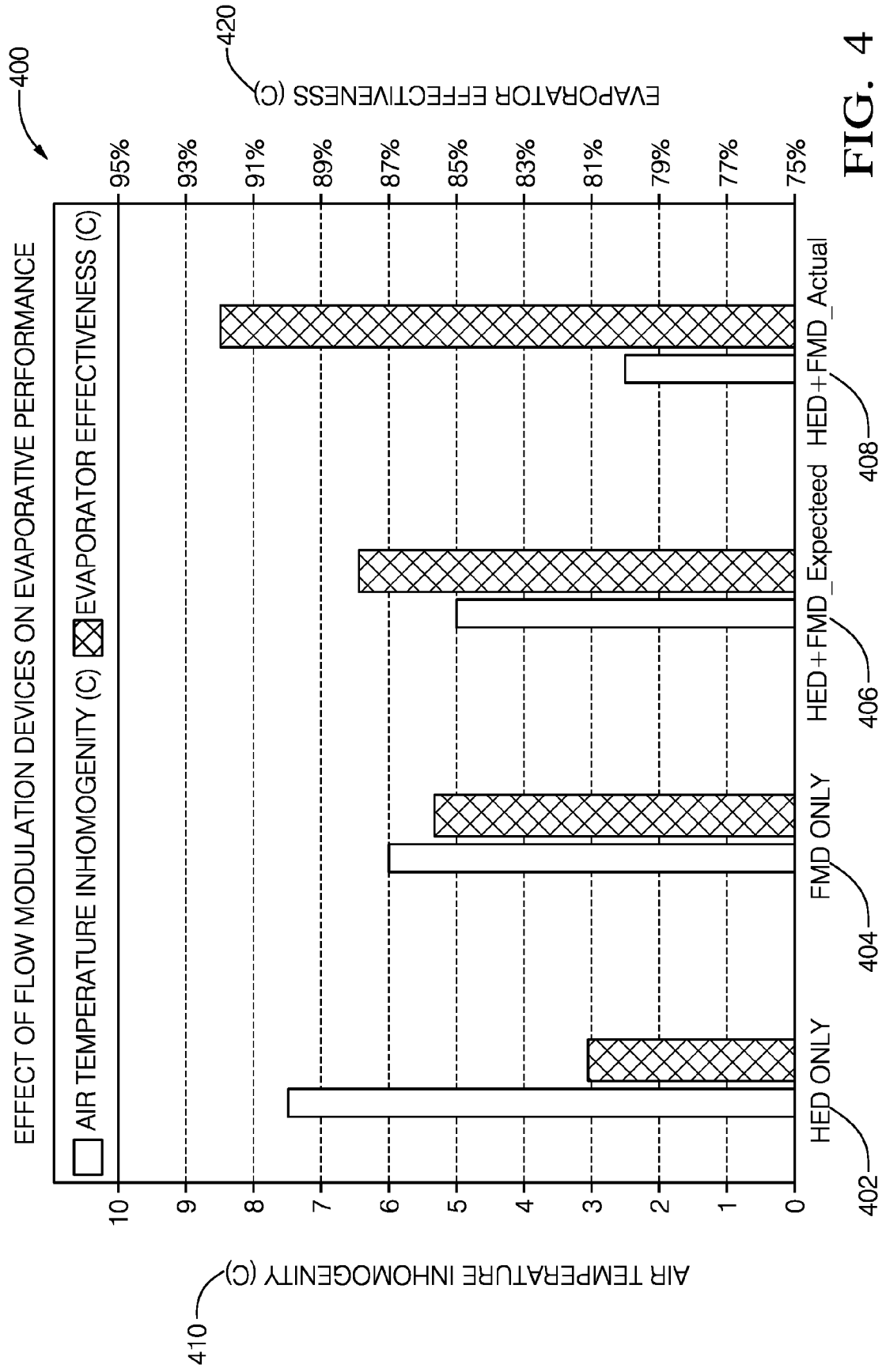


FIG. 4



EUROPEAN SEARCH REPORT

Application Number
EP 15 18 0761

5

10

15

20

25

30

35

40

45

50

55

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2010/089095 A1 (MACRI SALVATORE [IT] ET AL) 15 April 2010 (2010-04-15) * the whole document *	1-3	INV. F28F9/02 F28D1/053 F25B39/02 B60H1/00
X	US 2006/162918 A1 (HORIUCHI HIROFUMI [JP] ET AL) 27 July 2006 (2006-07-27) * paragraphs [0002], [0003], [0237] - [0278]; figures 1-6 *	1-3	
			TECHNICAL FIELDS SEARCHED (IPC)
			F28F F28D F25B B60H
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 16 December 2015	Examiner Leclaire, Thomas
CATEGORY OF CITED DOCUMENTS		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document			

EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 15 18 0761

5

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

16-12-2015

10

15

20

25

30

35

40

45

50

55

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2010089095 A1	15-04-2010	AT 556283 T	15-05-2012
		CN 101558277 A	14-10-2009
		DK 2079973 T3	13-08-2012
		EP 2079973 A2	22-07-2009
		ES 2387134 T3	14-09-2012
		HK 1138362 A1	30-08-2013
		US 2010089095 A1	15-04-2010
		WO 2008048505 A2	24-04-2008

US 2006162918 A1	27-07-2006	AT 422038 T	15-02-2009
		BR 0210482 A	10-08-2004
		CN 1516799 A	28-07-2004
		CZ 20033356 A3	10-11-2004
		EP 1397623 A1	17-03-2004
		KR 20040012939 A	11-02-2004
		TW 552382 B	11-09-2003
		US 2004159121 A1	19-08-2004
		US 2006162918 A1	27-07-2006
		WO 02103263 A1	27-12-2002

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- US 06987813 A [0001]