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(54) **HEAT TRANSFER TUBES**

(57) A heat transfer tube (100) includes a tube wall (102) defining a central axis in a lengthwise direction of the tube. The tube wall (102) includes a fluid inlet (104) and fluid outlet (106) for directing a coolant into and out of the tube (100). A hollow cone (110) is positioned within the tube wall (102) aligned with the central axis having an interior and exterior. A plurality of orifices (112) are defined through the cone (110) configured to provide a separation of liquid coolant and vapor within the tube (100).

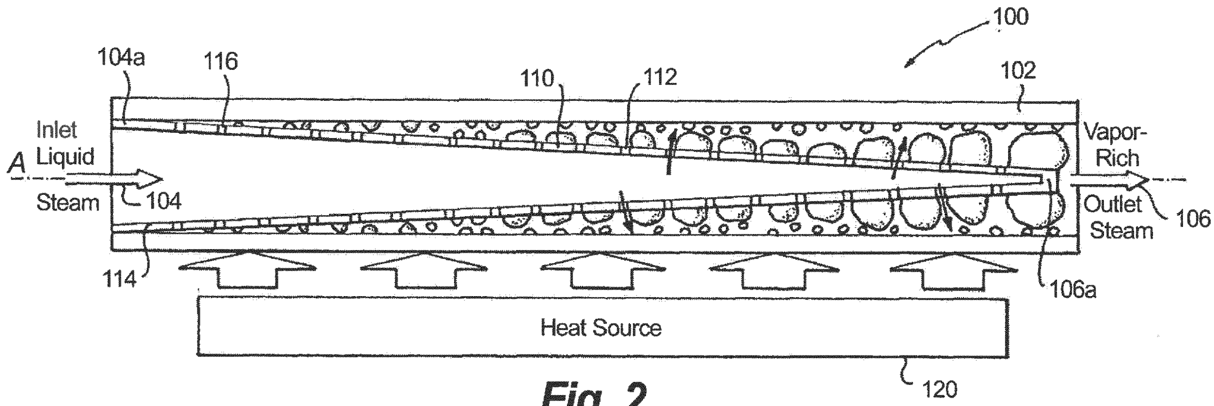

Fig. 2

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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present disclosure relates to heat exchangers, and more particularly to heat transfer tubes used with heat exchangers.

2. Description of Related Art

[0002] In-tube boiling is used in nearly all two-phase power and thermal management systems, such as, Rankine power cycles, HVAC vapor cycles thermal management, two-phase thermal buses and in many chemical processing applications. Boiling heat transfer is used to remove heat in cooling applications, for example, electronics cooling. High heat flux applications like high power lasers and microwaves rely on thermal management systems that employ two-phase cooling.

[0003] In-tube boiling can have very high heat transfer coefficients resulting in low wall temperature to fluid saturation temperature differences. However, in-tube boiling has several potential limitations. First, at high heat fluxes the voluminous vapor generated at the heated wall can block the free stream liquid from rewetting the wall. This well studied phenomenon is called Critical Heat Flux (CHF), or burnout. Secondly, boiling can be orientation and gravity sensitive. Beyond shear forces, gravity is the key force that motivates bubbles to leave the hot boiling surface. In adverse orientations, buoyancy forces tend to keep the vapor on the wall and thereby reduce the heat transfer coefficient and accelerate CHF conditions. For example, in reduced gravity environments buoyant forces do not exist and boiling heat transfer is severely limited. Many gravity insensitive geometries, like swirl flow inserts and curved channels that use centrifugal forces as a substitute for gravity have been used with limited success.

[0004] Such conventional methods and systems have generally been considered satisfactory for their intended purpose. However, there is still a need in the art for an improved heat transfer tubes. The present disclosure provides a solution for this need.

SUMMARY OF THE INVENTION

[0005] A heat transfer tube includes a tube wall defining a central axis in a lengthwise direction of the tube. The tube wall includes a fluid inlet and fluid outlet for directing a coolant into and out of the tube. A hollow cone is positioned within the tube wall aligned with the central axis having an interior and exterior. A plurality of orifices are defined through the cone configured to provide a separation of liquid coolant inside the cone from vapor outside the cone within the tube wall.

[0006] The orifices can be configured to form impingement jets of liquid directed from the interior of the cone towards the tube wall. The orifices can further be configured to allow vapor flow circumferentially and/or axially between the jets thereby allowing liquid coolant to impinge on the tube wall. The orifices can be dispersed throughout a length of the central cone.

[0007] The central cone can converge down in cross-sectional area in a downstream direction from an inlet end of the cone. The downstream end of the cone can be closed such that all fluid flow from the interior of the cone passes through the orifices and exits the tube wall from the outlet of the tube wall. Flow area of liquid coolant can decrease as a flow area of two-phase flow increases thereby making volumetric flow uniform within the tube. An outer surface of the tube is configured to be in thermal communication with a heat source. A heat exchanger can include a plurality of heat transfer tubes as described above.

[0008] A heat transfer device including a housing defining a central axis. The housing includes a fluid inlet and fluid outlet for directing a coolant into and out of the housing. A hollow insert within the housing aligned with the central axis having an interior and exterior. A plurality of orifices defined through the insert configured to provide a designed distribution of liquid coolant from the insert to the annular space that provides coolant for boiling at the outer surface and carries a vapor or vapor-liquid mixture axially outside the insert within the housing.

[0009] These and other features of the systems and methods of the subject disclosure will become more readily apparent to those skilled in the art from the following detailed description of the preferred embodiments taken in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] So that those skilled in the art to which the subject disclosure appertains will readily understand how to make and use the devices and methods of the subject disclosure without undue experimentation, preferred embodiments thereof will be described in detail herein below with reference to certain figures, wherein:

Fig. 1 is a cross-sectional view of a conventional boiling tube; and

Fig. 2 is a cross-sectional view of an exemplary embodiment of a heat transfer tube constructed in accordance with the present disclosure, showing a hollow cone within the tube wall.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0011] Reference will now be made to the drawings wherein like reference numerals identify similar structural features or aspects of the subject disclosure. For purposes of explanation and illustration, and not limitation, a partial view of an exemplary embodiment of a heat transfer tube in accordance with the disclosure is shown in Fig. 2 and is designated generally by reference character 100.

[0012] Fig. 1 illustrates a conventional boiling tube 10. In a horizontal orientation, several flow patterns develop as the quality (vapor fraction of total flow) increases. At low qualities bubbly flow dominates, followed by slug and plug (intermittent liquid and vapor bridges), annular flow and then a mist. These changes occur in a direction from left to right as oriented in Fig. 1

[0013] With reference to Fig. 2 a heat transfer tube 100 is shown in accordance with the present disclosure. The tube 100 can be part of a heat exchanger that is in communication with a heat source 120, for example, an electronic heat, a high heat flux load like a laser, or a hot fluid to be cooled. The tube 100 improves the boiling process while reducing heat transfer area, system weight, and increases system capabilities. The tube 100 includes a tube wall 102 defining a central axis A-A in a lengthwise direction. The tube wall 102 includes a fluid inlet 104 and fluid outlet 106 for directing a coolant into and out of the tube 100. A hollow cone 110 is positioned within the tube wall 102 aligned with the central axis. As shown in Fig. 2, the cone 110 converges down in a cross-sectional area in a downstream direction from the inlet end 104a of the cone 110 toward outlet 106.

[0014] A plurality of orifices 112 are defined through the cone 110 each extending from an interior 114 of the cone 110 to an exterior 116 of the cone 110. The downstream end 106a of the cone 110 is closed such that all fluid flow from the interior 114 of cone passes through the orifices and exits the tube 100 through the outlet 106. The plurality of orifices 112 are configured to provide a separation of liquid coolant within the cone 110 from vapor outside the cone 110 within the tube wall 102. More specifically, the orifices 112 are configured to form impingement jets of fluid directed from the interior 114 of the cone 110 towards the tube wall 102. The impingement of the jets increases the heat transfer coefficient, compared to conventional systems as shown in Fig. 1, and more importantly, keep the wall 102 wetted thereby greatly increasing critical heat flux (CHF). Vapor flows circumferentially and/or axially between the jets allowing the liquid coolant to impinge on tube wall 102. Very little distortion of the jets and degradation of its velocity occurs in areas of high quality (downstream) and void fraction (volume fraction of vapor). These "drier" areas are those that benefit most with respect to heat transfer coefficient and suppressing CHF, when compared to conventional systems as shown in Fig. 1. In regions where the two-phase flow is of lower quality (upstream) the jets may have less of an impact on heat transfer but are not at risk of CHF.

[0015] If the heat flux distribution is not circumferentially or axially symmetric, two design possibilities can be employed. First, the orifice distribution can also be made asymmetric so that orifice pattern produces a mass distribution for a better match the local heat fluxes. Secondly, the liquid distribution cone can be situated non-concentrically, with the orifice distribution providing a greater mass flux in the region that is closest to the heated outer wall. This embodiment provides better cooling where locally needed and extra flow space in other arcs to carry the spent vapor or liquid-vapor mixture.

[0016] The plurality of orifices 112 are disposed throughout the length of the central cone 110. The flow area of the orifices determines the jet velocity and pressure required for a given mass flow on an application by application basis. Fewer or smaller orifices will have higher velocity jets but a greater pressure drop. The size, number and distribution of the orifices can be optimized for any given application.

[0017] The impingement jets also make the heat transfer insensitive to orientation and gravity level. This feature and makes the device ideal for applications like microgravity. Additionally, due to the converging cross-sectional area of the cone 110, the flow area of the liquid coolant is decreasing while two-phase flow area is increasing. Pressure drops are reduced and the heat transfer is optimized by making the volumetric flow velocity more uniform in both regions comparted to conventional systems. Furthermore, the temperature of the liquid coolant supplied to the tube 100 does not significantly vary along the tube 100. To have this "fresh" coolant everywhere is advantageous, especially if the inlet flow is subcooled (below the saturation temperature). Subcooling increases the heat transfer coefficient and CHF.

[0018] This concept of impingement boiling may also be extended to a planar geometry. Fig. 2 can illustrate the planar concept as well as the cylindrical. For example, if the cross-section represents a slice in a two dimensional plane, then the heat transfer walls are flat surfaces rather than a cylindrical wall of a tube. Planar embodiments are suitable for many two-phase applications in thermal management, power and process heat transfer. They are also a good approach for phase management in reduced gravity environments.

[0019] The methods and systems of the present disclosure, as described above and shown in the drawings, provide for a device for increasing heat transfer with superior properties including the use of impingement gets to decrease central heat flux. While the apparatus and methods of the subject disclosure have been shown and described with reference to preferred embodiments, those skilled in the art will readily appreciate that changes and/or modifications may be made thereto without departing from the scope of the subject disclosure.

Claims

1. A heat transfer tube (100), comprising:

a tube wall (102) defining a central axis in a lengthwise direction of the tube (100), the tube wall (102) including a fluid inlet (104) and fluid

outlet (106) for directing a coolant into and out of the tube (100);
a hollow cone (110) within the tube wall (102) aligned with the central axis having an interior and exterior; and
a plurality of orifices (112) defined through the cone (110) configured to provide a separation of liquid coolant within the cone (110) from vapor outside the cone (110) within the tube wall (102).

2. The tube of claim 1, wherein the orifices (112) are configured to form impingement jets of fluid directed from the interior of the cone (110) towards the tube wall (102).

3. The tube of claim 2, wherein the orifices (112) are configured to flow vapor circumferentially and axially between the jets thereby allowing liquid coolant to impinge on the tube wall (102).

4. The tube of any preceding claim, wherein the central cone converges down in cross-sectional area in a downstream direction from an inlet end of the cone (110).

5. The tube of claim 4, wherein the downstream end of the cone (110) is closed such that all fluid flow from the interior of the cone (110) passes through the orifices (112) and exits the tube wall (102) from the outlet (106).

6. The tube of any preceding claim, wherein the orifices (112) are dispersed throughout a length of the central cone.

7. The tube of any preceding claim, wherein a flow area of liquid coolant decreases as a flow area of two-phase flow increases thereby making volumetric flow uniform within the tube wall (102).

8. The tube of any preceding claim, wherein an outer wall of the tube (100) is configured to be in communication with a heat source.

9. A heat exchanger, comprising:

a plurality of heat transfer tubes (100), each heat transfer tube (100), comprising:

a tube wall (102) defining a central axis in a lengthwise direction of the tube (100), the tube wall (102) including a fluid inlet (104) and fluid outlet (106) for directing a coolant into and out of the tube (100);
a hollow cone (110) within the tube wall aligned with the central axis having an interior and exterior; and
a plurality of orifices (112) defined through the cone (110) configured to provide separation of liquid coolant and vapor within the tube (100).

10. A heat transfer device, comprising:

a housing defining a central axis, the housing including a fluid inlet (104) and fluid outlet (106) for directing a coolant into and out of the housing;
a hollow insert within the housing aligned with the central axis having an interior and exterior; and
a plurality of orifices (112) defined through the insert configured to provide a designed distribution of liquid coolant from the insert to an annular space that provides coolant for boiling at an outer surface of the insert and carries a vapor or vapor-liquid mixture axially outside the insert within the housing.

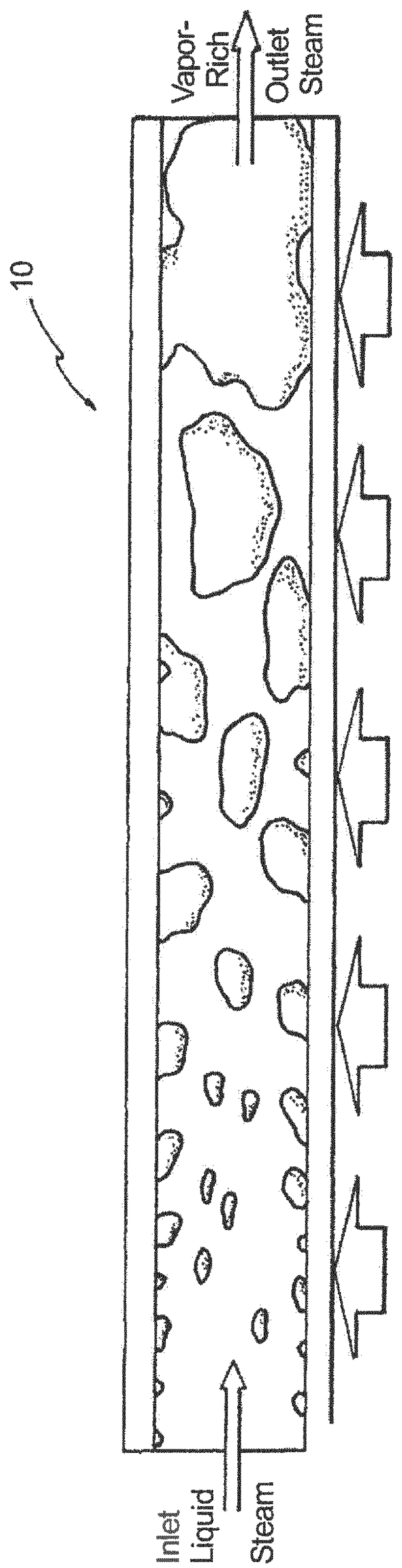

Fig. 1
(Prior Art)

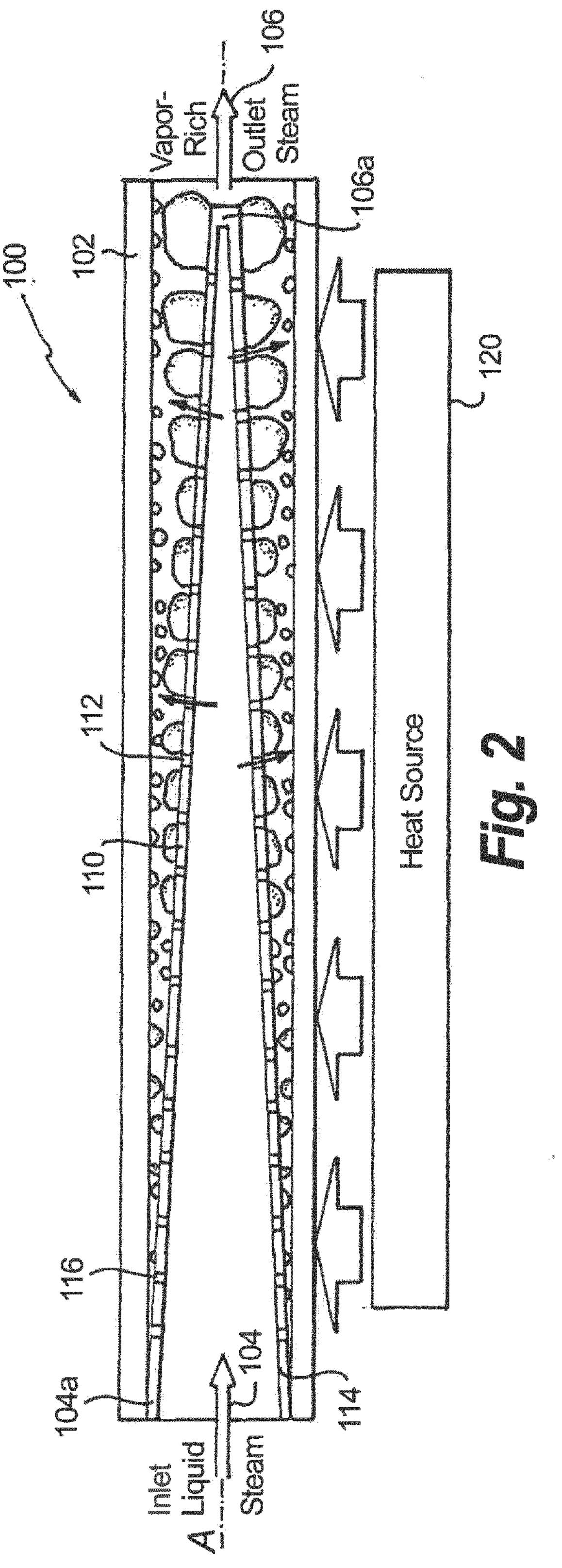

Fig. 2

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EUROPEAN SEARCH REPORT

Application Number
EP 16 19 1527

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	DE 255 445 C (LAMMERS HEINRICH) 9 January 1913 (1913-01-09) * the whole document * -----	1-10	INV. F28F13/00 F28F13/06 F28F1/40 F28F13/12
A	WO 2012/142932 A1 (BEIJING POWERTECH TECHNOLOGY CO LTD [CN]; LIU YANG [CN]) 26 October 2012 (2012-10-26) * abstract; figures 1-4 * -----	1-10	

TECHNICAL FIELDS SEARCHED (IPC)
F28F
F28D

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	12 December 2016	Bloch, Gregor

CATEGORY OF CITED DOCUMENTS

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

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

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 16 19 1527

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
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12-12-2016

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
DE 255445	C	09-01-1913	NONE	
WO 2012142932	A1	26-10-2012	CN 102748975 A	24-10-2012
			WO 2012142932 A1	26-10-2012

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82