(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 848 664 A1

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
14.07.2021 Bulletin 2021/28

(21) Application number: **19858007.8**

(22) Date of filing: **30.08.2019**

(51) Int Cl.:
F28F 1/42 *(2006.01)*

(86) International application number:
PCT/CN2019/103749

(87) International publication number:
WO 2020/048401 (12.03.2020 Gazette 2020/11)

(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
KH MA MD TN

(30) Priority: **05.09.2018 CN 201811030768**

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(54) **COMPACT GAS-GAS HEAT EXCHANGE TUBE AND MANUFACTURING AND USE METHODS THEREFOR**

(57) The present invention provides a compact gas-gas heat exchange tube. The heat exchange tube includes a heat transfer tube which is configured to separate an in-tube fluid from an out-tube fluid, and achieve, through convection and heat conduction manners, heat transfer between the in-tube fluid and the out-tube fluid; an inner fin set which is configured to expand a heat exchange surface on an inner side of the heat transfer tube, form a micro-channel to separate the in-tube fluid to make the same to axially flow along the heat transfer tube, and produce a turbulence effect and enhance heat convection as well; an outer fin set which is configured to expand a heat exchange surface on an outer side of the heat transfer tube, form a micro-channel to restrict the out-tube fluid from axially and reversely flowing along the heat transfer tube, and produce a turbulence effect and enhance heat convection as well, wherein a hole is provided on each fin of the inner fin set or/and the outer fin set. The present invention further provides methods for manufacturing and using the compact gas-gas heat exchange tube. The present invention realizes complete reverse flow and efficient heat transfer in a limited space and under a heat exchange working condition of a small tube number mean temperature difference, saves a spatial dimension of the apparatus, and reduces a weight of each area as well so as to reduce a total weight and a manufacturing cost.

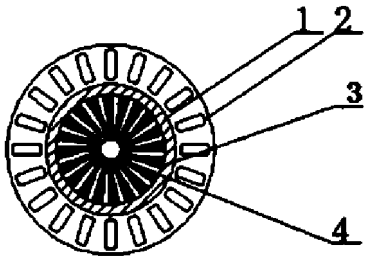

Fig. 2(a)

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Description

[0001] The present application claims the priority for Chinese Patent Application No. "201811030768.8", submitted to the Chinese Patent Office on September 5, 2018 and entitled "Compact Gas-Gas Heat Exchange Tube and Methods for Manufacturing and Using Same", which is incorporated herein in its entirety by reference.

FIELD OF TECHNOLOGY

[0002] The present invention relates to a heat exchange tube for heat transfer, in particular to a compact gas-gas heat exchange tube and methods for manufacturing and using the same, and belongs to the technical field of efficient and compact heat exchangers.

BACKGROUND

[0003] In recent years, new power cycle power generation technology has rapidly developed, and cycle power generation systems with working mediums of helium, hydrogen, carbon dioxide, organic compounds, etc. have emerged, among which the cycle system with a working medium of supercritical carbon dioxide is most promising. New application fields of the fourth generation nuclear power, solar thermal power generation, naval ships, etc. are developing Brayton cycle power generation technology based on supercritical carbon dioxide, as shown in Fig. 1. The carbon dioxide as a working medium in a cycle loop is in a supercritical state, and heat convection characteristics are similar to those of a high-pressure gas-gas heat exchanger.

[0004] In various heat exchangers used in industry, heat transfer tubes are basic heat exchange devices and widely applied to shell-and-tube heat exchangers, tube-sheet heat exchangers, finned tube heat exchangers, boilers, tubular heaters, etc. However, if conventional heat transfer tubes are used in supercritical carbon dioxide cycle devices, a heat transfer area will become vary large, such that the efficient heat exchange effect can't be realized in limited space, and the requirements of the supercritical carbon dioxide cycle devices in terms of efficiency and size can't be met either.

[0005] If fins are added to the heat transfer tubes, the heat transfer area can be expanded, the heat transfer surface and the heat transfer coefficient may be increased as well, so that the heat exchange performance can be improved. Planes of existing fins of finned tubes are perpendicular to the tubes axially, namely horizontal fins, and the finned tubes belong to incomplete reverse flow exchange.

SUMMARY

[0006] A technical problem to be solved by the present invention is how to realize complete reverse flow efficient heat transfer in a limited space and under a heat exchange working condition of a small tube number mean temperature difference.

[0007] To solve the above technical problem, a technical solution of the present invention is to provide a compact gas-gas heat exchange tube. The heat exchange tube includes:

[0008] a heat transfer tube, configured to separate an in-tube fluid from an out-tube fluid, and achieve, through convection and heat conduction manners, heat transfer between the in-tube fluid and the out-tube fluid;

[0009] an inner fin set, configured to expand a heat exchange surface on an inner side of the heat transfer tube to form a micro-channel with an equivalent diameter of 0.5 mm-5 mm, separate the in-tube fluid to make the same to axially flow along the heat transfer tube, and produce a turbulence effect and enhance heat convection as well;

[0010] an outer fin set, configured to expand a heat exchange surface on an outer side of the heat transfer tube, form a micro-channel to restrict the out-tube fluid from axially and reversely flowing along the heat transfer tube, and produce a turbulence effect and enhance heat convection as well,

[0011] wherein a hole is provided on each fin of the inner fin set or/and the outer fin set.

[0012] Preferably, a positioning tube configured to fix the inner fin set is arranged inside the heat transfer tube, the positioning tube being coaxially arranged inside the heat transfer tube, and one end of each fin in the inner fin set being connected to the positioning tube.

[0013] Preferably, a fin structure of the inner fin set is in a structure radically extending from a tube center to a tube wall.

[0014] Preferably, a fin structure of the inner fin set is in a Y-shaped structure.

[0015] Preferably, the inner fin set are metal sheets or metal strips radially parallel to the heat transfer tube, and the inner fin set is connected to an inner wall of the heat transfer tube.

[0016] Preferably, the inner fin set are metal sheets or metal strips arranged, around the positioning tube, in a circumferential structure, and surface of the metal sheets or the metal strips is axially parallel to the heat transfer tube.

[0017] Preferably, a width of the metal sheets or the metal strips accounts for 1/4-1 of an inner diameter of the heat transfer tube, and a thickness of the metal sheets or the metal strips is 0.2 mm-1.5 mm.

[0018] Preferably, the outer fin set are metal sheets or metal strips arranged, around the heat transfer tube, in a circumferential symmetric structure, and surface of the metal sheets or the metal strips is axially parallel to the heat transfer tube.

[0019] Preferably, the outer fin set are metal sheets or metal strips radially parallel to the heat transfer tube, and the outer fin set is connected to an outer wall of the heat transfer tube.

[0020] Preferably, a width of the metal sheets or the metal strips accounts for 1/4-1 of an inner diameter of the heat transfer tube, and a thickness of the metal sheets or the metal strip is 0.2 mm-3 mm.

[0021] Preferably, the hole on each fin of the inner fin set is in random shape, and the hole on each fin of the outer fin set is in random shape.

[0022] Preferably, the positioning tube is a hollowed tube.

[0023] Preferably, the heat transfer tube is a metal tube which may stand a specified temperature and pressure, and the metal tube may be a tube of any cross section or any profiled tube.

[0024] Preferably, the inner fin set and the outer fin set are made to be fixedly connected to the heat transfer tube.

[0025] The present invention provides a method for manufacturing the above compact gas-gas heat exchange tube. The method includes steps:

step 1: forming a heat transfer tube, among which the heat transfer tube is configured to separate an in-tube fluid from an out-tube fluid, and achieve, through convection and heat conduction manners, heat transfer between the in-tube fluid and the out-tube fluid;

step 2: arranging an inner fin set on a heat exchange surface on an inner side of the heat transfer tube, providing a hole on the inner fin set, among which the inner fin set is configured to expand a heat exchange surface on an inner side of the heat transfer tube to form a micro-channel with an equivalent diameter of 0.5 mm-5 mm, separate the in-tube fluid to make the same to axially flow along the heat transfer tube, and produce a turbulence effect and enhance heat convection as well;

and step 3: arranging an outer fin set on a heat exchange surface on an outer side of the heat transfer tube, providing a hole on the outer fin set, wherein the outer fin set is configured to expand the heat exchange surface on the outer side of the heat transfer tube, form a micro-channel to restrict the out-tube fluid from axially and reversely flowing along the heat transfer tube, and produce a turbulence effect and enhance heat convection as well.

[0026] The present invention further provides a method for manufacturing a compact gas-gas heat exchange tube. The method includes steps:

step 1: forming a heat transfer tube (1), wherein the heat transfer tube (1) is configured to separate an in-tube fluid from an out-tube fluid, and achieve, through convection and heat conduction manners, heat transfer between the in-tube fluid and the out-tube fluid;

step 2, arranging a positioning tube (4) configured to fix an inner fin set (3) inside the heat transfer tube (1), the positioning tube (4) being coaxially arranged inside the heat transfer tube (1);

step 3: arranging the inner fin set (3) on a heat exchange surface on an inner side of the heat transfer tube (1), connecting one end of each fin in the inner fin set (3) to the positioning tube (4), providing a hole on the inner fin set (3), wherein the inner fin set (3) is configured to expand the heat exchange surface on the inner side of the heat transfer tube (1) to form a micro-channel with an equivalent diameter of 0.5 mm-5 mm, separate the in-tube fluid to make the same to axially flow along the heat transfer tube (1), and produce a turbulence effect and enhance heat convection as well;

and step 4: arranging an outer fin set (2) on a heat exchange surface on an outer side of the heat transfer tube (1), and providing a hole on the outer fin set (2), wherein the outer fin set (2) is configured to expand the heat exchange surface on the outer side of the heat transfer tube (1) to form a micro-channel, restrict the out-tube fluid from axially and reversely flowing along the heat transfer tube (1), and produce a turbulence effect and enhance heat convection as well.

[0027] Preferably, in the two manufacturing method above, in step 2, the inner fin set (3) is connected to an inner wall of the heat transfer tube (1) fixing the outer fin set (2).

[0028] The present invention provides a method for using a compact gas-gas heat exchange tube equipped with a positioning tube. The method includes steps: arranging at least one heat transfer tube in a heat exchanger, wherein an in-tube fluid of the heat transfer tube is input through an in-tube fluid inlet end of the heat exchanger, flows, along an inner side of the heat transfer tube, to an outlet end of the heat transfer tube, and then flows to an in-tube fluid outlet end of the heat exchanger; in a flow process, the in-tube fluid of the heat transfer tube is subjected to a heat convection process with an inner fin set and an inner side surface of the heat transfer tube;

an out-tube fluid of the heat transfer tube is input through an out-tube fluid inlet end of the heat exchanger, flows, along

an outer side of the heat transfer tube, in a direction opposite that of the in-tube fluid of the heat transfer tube, and flows to an out-tube fluid outlet end of the heat exchanger; and in a flow process, the out-tube fluid of the heat transfer tube is subjected to a heat transfer process with the outer side surface of the heat transfer tube and the outer fin set, and a heat conduction process is generated among the outer fin set, the heat transfer tube and the inner fin set.

[0029] The present invention further provides a method for using the compact gas-gas heat exchange tube equipped with the positioning tube. The method includes steps: arranging at least one heat transfer tube in a heat exchanger, wherein an in-tube fluid of the heat transfer tube is input through an in-tube fluid inlet end of the heat exchanger, flows, along an inner side of the heat transfer tube, to an outlet end of the heat transfer tube, and then flows to an in-tube fluid outlet end of the heat exchanger; in a flow process, the in-tube fluid of the heat transfer tube is subjected to a heat convection process with an inner fin set, the positioning tube and an inner side surface of the heat transfer tube;
an out-tube fluid of the heat transfer tube is input from an out-tube fluid inlet end of the heat exchanger, flows, along an outer side of the heat transfer tube, in a direction opposite that of the in-tube fluid of the heat transfer tube, and flows to an out-tube fluid outlet end of the heat exchanger; and in the flow process, the out-tube fluid of the heat transfer tube is subjected to a heat conduction process with an outer side surface of the heat transfer tube and the outer fin set, and a heat conduction process is generated among the outer fin set , the heat transfer tube, the inner fin set and the positioning tube.

[0030] Preferably, under the condition that a hole is provided on a fin of the inner fin set, the in-tube fluid of the heat transfer tube flows through the hole on the fin of the inner fin set and axially flows along the heat transfer tube; under the condition that a hole is provided on a fin of the outer fin set, the out-tube fluid of the heat transfer tube flows through the hole on the fin of the outer fin set and axially flows along the heat transfer tube;

[0031] reverse flow heat exchange is performed between the in-tube fluid and the out-tube fluid of the heat transfer tube; a heat exchange surface on an inner side of the heat transfer tube is expanded by the inner fin set, a micro-channel is formed to restrict the in-tube fluid from axially and reversely flowing along the heat transfer tube, and a turbulence effect is produced and heat convection is enhanced as well; and a heat exchange surface on an outer side of the heat transfer tube is expanded by the outer fin set, a micro-channel is formed to restrict the out-tube fluid from axially and reversely flowing along the heat transfer tube, and a turbulence effect is produced and heat convection is enhanced as well.

[0032] Compared with the prior art, the compact gas-gas heat exchange tube provided by the present invention has the following beneficial effects:
the present invention provides the compact gas-gas heat exchanger, which realizes complete reverse flow efficient heat transfer in a limited space and under a heat exchange working condition of a small tube number mean temperature difference.

1. complete reverse flow heat exchange is achieved between the in-tube fluid and the out-tube fluid, and heat transfer may be achieved under the relatively small tube number mean temperature difference.
2. Different fin set structures are arranged along an inner surface and an outer surface of the heat transfer tube, thereby achieving a sufficient turbulence effect, improving a heat convection coefficient, and effectively expanding a heat exchange superficial area.
3. The micro-channel with the equivalent diameter of 0.5 mm-5 mm may well achieve improvement of heat transfer efficiency, thereby producing a certain turbulence effect, and sufficiently reducing a weight of the heat transfer tube.
4. The heat exchange tube may be used for manufacturing an efficient and compact heat exchanger, particularly applied to a gas-gas heat exchange working condition or a regenerator.
5. The present invention will provide sufficient effective heat exchange areas and compactly arrange the areas together, thereby saving a spatial size of the apparatus, and reducing a weight of each area as well and therefore reducing a total weight and a manufacturing cost of the apparatus.

BRIEF DESCRIPTION OF THE DRAWINGS

[0033]

Fig. 1 is a schematic diagram of an supercritical carbon dioxide cycle system;
Fig. 2 is a schematic diagram, (a) section view, and (b) front view of an externally-horizontal-fin and internally-vertical-fin compact gas-gas heat exchange tube provided by embodiment 1;
Fig. 3 is a schematic diagram, (a) section view, and (b) front view of an externally-horizontal-fin and internally-vertical-fin compact gas-gas heat exchange tube provided by embodiment 2;
Fig. 4 is a schematic diagram, (a) section view, and (b) front view of an externally-horizontal-fin and internally-horizontal-fin compact gas-gas heat exchange tube provided by embodiment 3;
Fig. 5 is a schematic diagram, (a) section view, and (b) front view of an externally-horizontal-fin and internally-horizontal-fin compact gas-gas heat exchange tube provided by embodiment 4;

Fig. 6 is a schematic diagram, (a) section view, and (b) front view of an externally-vertical-fin and internally-vertical-fin compact gas-gas heat exchange tube provided by embodiment 5;
Fig. 7 is an expanded schematic diagram of an externally-vertical-fin and internally-vertical-fin circular tube in embodiment 5;
Fig. 8 is a schematic diagram, (a) section view, and (b) front view of the externally-vertically-fin and internally-horizontal-fin compact gas-gas heat exchange tube provided by embodiment 6;
Fig. 9 is a structural schematic diagram of a micro-channel heat exchanger;
Fig. 10 is a structural schematic diagram of a printed circuit board; and
Fig. 11 is an overall schematic diagram of a heat exchanger;

Description of reference numerals:

[0034] 1-heat transfer tube, 2-outer fin set, 3-inner fin set, and 4-positioning tube.

DESCRIPTION OF THE EMBODIMENTS

[0035] Hereinafter, the present invention will be further described in conjunction with particular embodiments.

Embodiment 1

[0036] Fig. 2 is a schematic diagram of a compact gas-gas heat exchange tube provided by this embodiment. The compact gas-gas heat exchange tube includes:

a heat transfer tube 1:
an outer fin set 2 which is arranged on a heat exchange surface on an outer side of the heat transfer tube 1 and is configured to form a micro-channel with an equivalent diameter of 0.5 mm, and restrict an out-tube fluid from axially flowing along the heat transfer tube 1. Each outer fin of the outer fin set 2aremetal sheets which are radically parallel to the heat transfer tube 1, a width of the metal sheets accounting for 1/4 of an inner diameter of the heat transfer tube 1, and a thickness is 1 mm. A hole is provided on each fin of the outer fin set 2, and when the out-tube fluid flows through the outer fin and the hole on the outer fin, a turbulence effect is produced and heat convection is enhanced; and
an inner fin set 3 which is arranged on a heat exchange surface on an inner side of the heat transfer tube 1 and is configured to form a micro-channel with an equivalent diameter of 0.5 mm, and separate an in-tube fluid to make the same to axially flow along the heat transfer tube 1. Each outer fin of the inner fin set 3 are metal sheets which are axially parallel to the heat transfer tube 1, a width of the metal sheets accounting for 1/4 of an inner diameter of the heat transfer tube 1, and a thickness being 1 mm. Each fin of the inner fin set 3 forms an end to be connected to a positioning tube 4, and the other end is in a diffusion shape extending to a tube wall of the heat transfer tube 1. A hole is provided on each fin of the inner fin set 3, and when the in-tube fluid flows through the inner fin and the hole on the outer fin, a turbulence effect is produced and heat convection is enhanced.

[0037] In some embodiments, the heat exchange tube is further characterized in one or more points below, which may be combined in any quantity and sequence, for example, one end, extending to an inner wall of the heat transfer tube 1, of each fin of the inner fin set 3 may be connected to the heat transfer tube 1, or not, and the positioning tube 4 may be selected from a solid tube or a hollowed tube.

[0038] Embodiment 2

[0039] Fig. 3 is a schematic diagram of a compact gas-gas heat exchange tube provided by this embodiment. The compact gas-gas heat exchange tube includes:

a heat transfer tube 1:
an outer fin set 2 which is arranged on a heat exchange surface on an outer side of a heat transfer tube 1 and is configured to form a micro-channel with an equivalent diameter of 0.5 mm-1 mm, and restrict an out-tube fluid from axially flowing along the heat transfer tube 1. Each outer fin of the outer fin set 2 are metal strips which are radically parallel to the heat transfer tube 1, a width of the metal strips accounting for 1/2 of an inner diameter of the heat transfer tube 1, and a thickness being 0.5 mm. A hole is provided on each fin of the outer fin set 2, and when the out-tube fluid flows through the outer fin and the hole on the outer fin, a turbulence effect is produced and heat convection is enhanced; and
an inner fin set 3 which is arranged on a heat exchange surface on an inner side of the heat transfer tube 1 and is configured to form a micro-channel with an equivalent diameter of 1 mm, and separate an in-tube fluid to make the

same to axially flow along the heat transfer tube 1. Each inner fin of the inners fin set 3 is an Y-shaped metal sheet which is axially parallel to the heat transfer tube 1, a width of the metal sheets accounting for 1/2 of an inner diameter of the heat transfer tube 1, and a thickness being 0.5mm. An end of the inner fin set 3 is connected to a positioning tube 4, and the other end extends to a tube wall of the heat transfer tube 1. A hole is provided on each fin of the inner fin set 3, and when the in-tube fluid flows through the inner fin and the hole on the inner fin, a turbulence effect is produced and heat convection is enhanced.

[0040] In some embodiments, the heat exchange tube is further characterized in one or more points below, which may be combined in any quantity and sequence, for example, one end, extending to an inner wall of the heat transfer tube 1, of each fin of the inner fin set 3 may be connected to the heat exchange tube 1, or not, and the positioning tube 4 may be selected from a solid tube or a hollowed tube.

Embodiment 3

[0041] Fig. 4 is a schematic diagram of a compact gas-gas heat exchange tube provided by this embodiment. The compact gas-gas heat exchange tube includes:

a heat transfer tube 1:
and an outer fin set 2 which is arranged on a heat exchange surface on an outer side of the heat transfer tube 1 and is configured to form a micro-channel with an equivalent diameter of 2 mm, and restrict an out-tube fluid from axially flowing along the heat transfer tube 1. Each outer fin of the outer fin set 2 are metal sheets which are radically parallel to the heat transfer tube 1, a width of the metal sheets accounting for 1/3 of an inner diameter of the heat transfer tube 1, and a thickness is 1.5 mm. An oval hole is provided on each fin of the outer fin set 2, and when the out-tube fluid flows through the outer fin and the hole on the outer fin, a turbulence effect is produced and heat convection is enhanced; and
an inner fin set 3 which is arranged on a heat exchange surface on an inner side of the heat transfer tube 1 and is configured to form a micro-channel with an equivalent diameter of 1 mm, and separate an in-tube fluid to make the same to axially flow along the heat transfer tube 1. Each fin of the inner fin set 3 are metal sheets which are radically parallel to the heat transfer tube 1, a width of the metal sheets being same to an inner diameter of the heat transfer tube 1, and a thickness being 1.5 mm. An oval hole is provided on each fin of the inner fin set 3, and when the in-tube fluid flows through the inner fin and the hole on the inner fin, a turbulence effect is produced and heat convection is enhanced; and

[0042] In some embodiments, the heat exchange tube is further characterized in one or more points below, which may be combined in any quantity and sequence, for example, one end, extending to an inner wall of the heat transfer tube 1, of each fin of the inner fin set 3 may be connected to the heat transfer tube 1, or not, and the holes of each fin of the inner fin set 3 may be symmetrically arranged, or randomly arranged.

Embodiment 4

[0043] Fig. 5 is a schematic diagram of a compact gas-gas heat exchange tube provided by this embodiment. The compact gas-gas heat exchange tube includes:

a heat transfer tube 1:
an outer fin set 2 which is arranged on a heat exchange surface on an outer side of the heat transfer tube 1 and is configured to form a micro-channel with an equivalent diameter of 2 mm-4 mm, and restrict an out-tube fluid from axially flowing along the heat transfer tube 1. Each outer fin of the outer fin set 2 are metal sheets which are radically parallel to the heat transfer tube 1, a width of the metal sheets accounting for 2/3 of an inner diameter of the heat transfer tube 1, and a thickness being 0.8 mm. An oval hole is provided on each fin of the outer fin set 2, and when the out-tube fluid flows through the outer fin and the hole on the outer fin, a turbulence effect is produced and heat convection is enhanced; and
an inner fin set 3 which is arranged on a heat exchange surface on an inner side of the heat transfer tube 1 and is configured to form a micro-channel with an equivalent diameter of 2 mm, and separate an in-tube fluid to make the same to axially flow along the heat transfer tube 1. Each fin of the inner fin set 3 are metal sheets which are radically parallel to the heat transfer tube 1, a width of the metal sheets being same to an inner diameter of the heat transfer tube 1, and a thickness being 2.5 mm. A round hole is provided on each fin of the inner fin set 3, and when the in-tube fluid flows through the inner fin and the hole on the inner fin, a turbulence effect is produced and heat convection is enhanced; and

[0044] In some embodiments, the heat exchange tube is further characterized in one or more points below, which may be combined in any quantity and sequence, for example, one end, extending to an inner wall of the heat transfer tube 1, of each fin of the inner fin set 3 may be connected to the heat exchange tube, or not, and the holes of each fin of the inner fin set 3 may be symmetrically arranged, or randomly arranged.

Embodiment 5

[0045] Fig. 6 is a schematic diagram of a compact gas-gas heat exchange tube provided by this embodiment. The compact gas-gas heat exchange tube includes:

a heat transfer tube 1:
an outer fin set 2 which is arranged on a heat exchange surface on an outer side of the heat transfer tube 1 and is configured to form a micro-channel with an equivalent diameter of 3 mm-5 mm, and restrict an out-tube fluid from axially flowing along the heat transfer tube 1. Each outer fin of the outer fin set 2 are metal sheets which are axially parallel to the heat transfer tube 1, a width of the metal sheets accounting for 3/4 of an inner diameter of the heat transfer tube 1, and a thickness being 1.5 mm. A hole is provided on each fin of the outer fin set 2, and when the out-tube fluid flows through the outer fin and the hole on the outer fin, a turbulence effect is produced and heat convection is enhanced; and
an inner fin set 3 which is arranged on a heat exchange surface on an inner side of the heat transfer tube 1 and is configured to form a micro-channel with an equivalent diameter of 1.5 mm, and separate an in-tube fluid to make the same to axially flow along the heat transfer tube 1. Each fin of the inner fin set 3 are metal sheets which are axially parallel to the heat transfer tube 1. Each fin of the inner fin set 3 forms an end to be connected to a positioning tube 4, and the other end is in a diffusion shape extending, from the center to the periphery, to a tube wall of the heat transfer tube. A hole is provided on each fin of the inner fin set 3, and when the in-tube fluid flows through the inner fin and the hole on the inner fin, a turbulence effect is produced and heat convection is enhanced.

[0046] Fig. 7 is an expanded schematic diagram of an externally-vertical-fin and internally-vertical-fin circular tube. In Fig. 7, a represents an equivalent diameter of the inner fin 3, b represents an equivalent diameter of the outer fin 2, and t represents a wall thickness of the heat transfer tube 1.

[0047] In some embodiments, the heat exchange tube is further characterized in one or more points below, which may be combined in any quantity and sequence. One end, extending to an inner wall of the heat transfer tube, of each fin of the inner fin set 3 may be connected to the heat transfer tube, or not, for example: the positioning tube 4 may be selected from a solid tube or a hollowed tube, and the holes of each fin of the outer fin set 2 or the holes of each fin of the inner fin set 3 may be symmetrically arranged, or randomly arranged.

Embodiment 6

[0048] Fig. 8 is a schematic diagram of a compact gas-gas heat exchange tube provided by this embodiment. The compact gas-gas heat exchange tube includes:

a heat transfer tube 1:
an outer fin set 2 which is arranged on a heat exchange surface on an outer side of the heat transfer tube 1 and is configured to form a micro-channel with an equivalent diameter of 3 mm-5 mm, and restrict an out-tube fluid from axially flowing along the heat transfer tube 1. Each outer fin of the outer fin set 2 are metal sheets which are radically parallel to the heat transfer tube 1, a width of the metal sheets being same to an inner diameter of the heat transfer tube 1, and a thickness being 1.2 mm. A hole is provided on each fin of the outer fin set 2, and when the out-tube fluid flows through the outer fin and the hole on the outer fin, a turbulence effect is produced and heat convection is enhanced; and
an inner fin set 3 which is arranged on a heat exchange surface on an inner side of the heat transfer tube 1 and is configured to form a micro-channel with an equivalent diameter of 1 mm, and separate an in-tube fluid to make the same to axially flow along the heat transfer tube 1. Each fin of the inner fin set 3 are metal sheets which are radially parallel to the heat transfer tube 1, a width of the metal sheets being same to an inner diameter of the heat transfer tube 1, and a thickness being 3 mm. An oval hole is provided on each fin of the inner fin set 3, and when the in-tube fluid flows through the inner fin and the hole on the inner fin, a turbulence effect is produced and heat convection is enhanced.

[0049] In some embodiments, the heat exchange tube is further characterized in one or more points below, which may be combined in any quantity and sequence, for example, one end, extending to an inner wall of the heat transfer

tube, of each fin of the inner fin set 3 may be connected to the heat transfer tube, or not. The holes of each fin of the inner fin set 3 may be symmetrically arranged, or randomly arranged.

Embodiment 7

[0050] This embodiment provides a method for manufacturing a compact gas-gas heat exchange tube:

step 1: forming a heat transfer tube 1, among which the heat transfer tube 1 is configured to separate an in-tube fluid from an out-tube fluid, and achieve, through convection and heat conduction manners, heat transfer between the in-tube fluid and the out-tube fluid;
step 2: arranging an inner fin set 3 on a heat exchange surface on an inner side of the heat transfer tube 1, among which the inner fin set 3 is configured to expand the heat exchange surface on the inner side of the heat transfer tube 1 to form a micro-channel with an equivalent diameter of 0.5 mm-5 mm, separate the in-tube fluid to make the same to axially flow along the heat transfer tube 1, and produce a turbulence effect and enhance heat convection as well;
and step 3: arranging an outer fin set 2 on a heat exchange surface on an outer side of the heat transfer tube 1, among which the outer fin set 2 is configured to expand the heat exchange surface on the outer side of the heat transfer tube 1 to form a micro-channel, restrict the out-tube fluid from axially and reversely flowing along the heat transfer tube 1, and produce a turbulence effect and enhance heat convection as well, and
providing a hole on the inner fin set 3 or/and the outer fin set 2.

[0051] The manufacturing method may be combined, in any quantity and sequence, with one or more relevant limits below.

[0052] In one or more embodiments, a positioning tube 4 configured to fix the inner fin set 3 is arranged inside the heat transfer tube 1, the positioning tube 4 being coaxially arranged inside the heat transfer tube 1, and one end of each fin in the inner fin set 3 being connected to the positioning tube 4.

[0053] In one or more embodiments, the inner fin set 3 is connected to an inner wall of the heat transfer tube 1, which fixedly connected to the outer fin set 2.

[0054] In combination with Fig. 11, this embodiment further provides a method for using the above compact gas-gas heat exchange tube. The method includes the following steps:

step 1: machining the above heat transfer tube into that with required specifications according to whole design of an heat exchanger, which includes a specification of the heat transfer tube, a specification of the inner fin set and a specification of the outer fin set, and mounting the heat transfer tube as a member, in the heat exchanger (for example, manufacturing it into a tube bundle of a shell-and-tube heat exchanger). In the heat exchanger, middle M is an inner-outer fin zone, where a heat exchange tube with inner and outer fins is used, both ends S are fin-free zones, where fin-free heat exchange tubes are used.
Step 2: arranging at least one heat transfer tube 1 in a housing of the shell-and-tube heat exchanger, an inner fluid of the heat transfer tube 1 is input through an in-tube fluid inlet end 5 (for example, an inlet of a header of the shell-and-tube heat exchanger) of the heat exchanger, and flows, along an inner side of the heat transfer tube 1, to an outlet end of the heat transfer tube 1, during a flow process, the in-tube fluid of the heat transfer tube 1 is subjected to a heat transfer process with an inner side surface of the heat transfer tube 1; an outer fluid of the heat transfer tube 1 is input from an out-tube fluid inlet end 7 (for example, an inlet of the housing of the shell-and-tube heat exchanger) of the heat exchanger, flows, along an outer side of the heat transfer tube 1, in a direction opposite that of the in-tube fluid, and flows to an out-tube fluid outlet end 8 of the heat exchanger; an in-tube fluid is input through the in-tube fluid inlet end 5 of the heat exchanger, flows, along an inner side of the heat transfer tube, in a direction opposite that of the out-tube fluid, and flows to an in-tube fluid outlet end 6 of the heat exchanger; and the out-tube fluid of the heat transfer tube 1 is subjected to an heat transfer process with an outer side surface of the heat transfer tube 1 and the outer fin set, the heat transfer tube and the outer fin set are subjected to a heat conduction process with the inner fin set, and the in-tube fluid is subjected to a heat transfer process with the inner side surface of the heat transfer tube, and the inner fin set.

[0055] In one or more embodiments, an in-tube fluid of each heat transfer tube 1 is input through the inlet end (for example, the inlet of the header of the shell-and-tube heat exchanger) of the heat transfer tube 1, and flows, along the inner side of the heat transfer tube 1, to the outer end of the heat transfer tube 1. In a flow process, the in-tube fluid of the heat transfer tube 1 is subjected to heat convection and heat transfer process with the inner fin set of the heat transfer tube 1, the positioning tube and the inner side surface of the heat transfer tube.

[0056] The out-tube fluid of the heat transfer tube 1 is input through the out-tube fluid inlet end (for example, the inlet

of the housing of the shell-and-tube heat exchanger) of the heat exchanger, flows, along the outer side of the heat transfer tube 1, in a direction opposite that of the in-tube fluid of the heat transfer tube 1, and flows to the out-tube fluid outlet end of the heat exchanger. The out-tube fluid flows through the hole of the outer fin set, and axially flow along the heat transfer tube 1. In the flow process, the out-tube fluid is subjected to the heat transfer process with the outer side surface of the heat transfer tube 1 and the outer fin set, and a heat transfer process is performed among the outer fin set, the heat transfer tube and the inner fin set and the positioning tube.

[0057] Fig. 9 is a structural schematic diagram of a micro-channel heat exchanger. In the figure, c represents a horizontal equivalent diameter of a micro-channel heat exchanger, and d represents a vertical equivalent diameter of the micro-channel heat exchanger.

[0058] Fig. 10 is a structural schematic diagram of a printed circuit board. In the figure, e represents an equivalent diameter of a printed circuit board type heat exchanger.

[0059] Hereinafter, an equivalent diameter of 2 mm and the same unit size are taken as an example for calculating a compact degree of three structures of heat exchangers, which is represented by a superficial area, namely a surface density (m2/m3), of a solid in contact with gas in a unit size:

Fig. 7 is a structure of an inner-outer-fin tube		Fig. 9 is a micro-tube structure	Fig. 10 is a printed circuit board-type structure
Not perforated 900m^2/m^3	Perforated 1200-1500 m^2/m^3	1099 m^2/m^3	1058 m^2/m^3

[0060] It may be seen from the above calculation results that the compact degree is comparable to that of another method, and after a hole structure is used, the surface density per unit size gets obviously enhanced, and a flowing-around enhancing effect is generated as well. The heat exchanger apparatus manufactured by the present invention may achieve a smaller contour size and a smaller weight.

[0061] What is described above is merely a preferred embodiment of the present invention, rather than a limit of any form or a substantial limit to the present invention. It shall be noted that for those of ordinary skill in the art, they may make several improvements and supplements on the premise without deviating from the method of the present invention, and these improvements and supplements shall be considered to fall within the scope of protection of the present invention. For those of skill in the art who are familiar with the profession, they may make some alterations, modifications and evolutions of equivalent changing by utilizing the disclosed technical content above under the condition without deviating from the spirits and scope of the present invention, which shall be equivalent embodiments of the present invention; and meanwhile, any alteration, modification and evolution of equivalent changing on the above embodiments based on the substantial technologies of the present invention shall still fall within the scope of a technical solution of the present invention.

Claims

1. A compact gas-gas heat exchange tube, **characterized in that** it comprises: a heat transfer tube (1) which is configured to separate an in-tube fluid from an out-tube fluid, and achieve, through convection and heat conduction manners, heat transfer between the in-tube fluid and the out-tube fluid; an inner fin set (3) which is configured to expand a heat exchange surface on an inner side of the heat transfer tube (1), form a micro-channel with an equivalent diameter of 0.5 mm-5 mm, separate the in-tube fluid to make the same to axially flow along the heat transfer tube (1), and produce a turbulence effect and enhance heat convection as well; an outer fin set (2) which is configured to expand a heat exchange surface on an outer side of the heat transfer tube (1), form a micro-channel, restrict the out-tube fluid from axially and reversely flowing along the heat transfer tube (1), and produce a turbulence effect and enhance heat convection as well, wherein a hole is provided on each fin of the inner fin set (3) or/and the outer fin set (2).

2. The compact gas-gas heat exchange tube according to claim 1, **characterized in that** a positioning tube (4) configured to fix the inner fin set (3) is arranged inside the heat transfer tube (1), the positioning tube (4) being coaxially arranged inside the heat transfer tube (1), and one end of each fin in the inner fin set (3) being connected to the positioning tube (4).

3. The compact gas-gas heat exchange tube according to claim 1, **characterized in that** a fin structure of the inner fin set (3) is in a structure radically extending from a tube center to a tube wall.

4. The compact gas-gas heat exchange tube according to claim 1, **characterized in that** a fin of the inner fin set (3) is in a Y-shaped structure.

5. The compact gas-gas heat exchange tube according to claim 1, **characterized in that** the inner fin set (3) are metal sheets or metal strips radially parallel to the heat transfer tube (1), and the inner fin set (3) is connected to an inner wall of the heat transfer tube (1).

6. The compact gas-gas heat exchange tube according to claim 2, **characterized in that** the inner fin set (3) is arranged, around the positioning tube (4), to be metal sheets or metal strips in a circumferential structure, and a surface of the metal sheets or the metal strips is axially parallel to the heat transfer tube (1).

7. The compact gas-gas heat exchange tube according to claim 5 or 6, **characterized in that** a width of the metal sheets or the metal strips accounts for 1/4-1 of an inner diameter of the heat transfer tube, and a thickness of the metal sheets or the metal strips is 0.2 mm-1.5 mm.

8. The compact gas-gas heat exchange tube according to claim 1, **characterized in that** the outer fin set (2) is arranged, around the heat transfer tube (1), to be metal sheets or metal strips in a circumferential symmetric structure, and a surface of the metal sheets or the metal strips is axially parallel to the heat transfer tube (1).

9. The compact gas-gas heat exchange tube according to claim 1, **characterized in that** the outer fin set (2) are metal sheets or metal strips radially parallel to the heat transfer tube (1), and the outer fin set (2) is connected to an outer wall of the heat transfer tube (1).

10. The compact gas-gas heat exchange tube according to claim 8 or 9, **characterized in that** a width of the metal sheets or the metal strips accounts for 1/4-1 of an inner diameter of the heat transfer tube, and a thickness of the metal sheets or the metal strips is 0.2 mm-3 mm.

11. The compact gas-gas heat exchange tube according to claim 2, **characterized in that** the positioning tube (4) is a hollowed tube.

12. The compact gas-gas heat exchange tube according to claim 1, **characterized in that** the heat transfer tube (1) is a metal tube.

13. The compact gas-gas heat exchange tube according to claim 1, **characterized in that** both the inner fin set (3) and the outer fin set (2) are fixedly connected to the heat transfer tube (1).

14. A method for manufacturing the compact gas-gas heat exchange tube as defined in claim 1, **characterized in that** it comprises steps: step 1: forming a heat transfer tube (1), wherein the heat transfer tube (1) is configured to separate an in-tube fluid from an out-tube fluid, and achieve, through convection and heat conduction manners, heat transfer between the in-tube fluid and the out-tube fluid; step 2: arranging an inner fin set (3) on a heat exchange surface on an inner side of the heat transfer tube (1), and providing a hole on the inner fin set (3); wherein the inner fin set (3) is configured to expand the heat exchange surface on the inner side of the heat transfer tube (1) to form a micro-channel with an equivalent diameter of 0.5 mm-5 mm, separate the in-tube fluid to make the same to axially flow along the heat transfer tube (1), and produce a turbulence effect and enhance heat convection as well; and step 3: arranging an outer fin set (2) on a heat exchange surface on an outer side of the heat transfer tube (1), and providing a hole on the outer fin set (2); wherein the outer fin set (2) is configured to expand the heat exchange surface on the outer side of the heat transfer tube (1) to form a micro-channel, restrict the out-tube fluid from axially and reversely flowing along the heat transfer tube (1), and produce a turbulence effect and enhance heat convection as well.

15. A method for manufacturing the compact gas-gas heat exchange tube as defined in claim 2, **characterized in that** it comprises steps: step 1: forming a heat transfer tube (1), wherein the heat transfer tube (1) is configured to separate an in-tube fluid from an out-tube fluid, and achieve, through convection and heat conduction manners, heat transfer between the in-tube fluid and the out-tube fluid; step 2: arranging a positioning tube (4) configured to fix the inner fin set (3) inside the heat transfer tube (1), wherein the positioning tube (4) is coaxially arranged inside the heat transfer tube (1); step 3: arranging the inner fin set (3) on a heat exchange surface on an inner side of the heat transfer tube (1), wherein one end of each fin in the inner fin set (3) is connected to the positioning tube (4); providing a hole on the inner fin set (3), wherein the inner fin set (3) is configured to expand the heat exchange surface on the inner side of the heat transfer tube (1) to form a micro-channel with an equivalent diameter of 0.5 mm-5 mm,

separate the in-tube fluid to make the same to axially flow along the heat transfer tube (1), and produce a turbulence effect and enhance heat convection as well; and step 4: arranging an outer fin set (2) on a heat exchange surface on an outer side of the heat transfer tube (1), providing a hole on the outer fin set (2), wherein the outer fin set (2) is configured to expand the heat exchange surface on the outer side of the heat transfer tube (1) to form a micro-channel, restrict the out-tube fluid from axially and reversely flowing along the heat transfer tube (1), and produce a turbulence effect and enhance heat convection as well.

16. The method for manufacturing the compact gas-gas heat exchange tube according to claim 14 or 15, **characterized in that** in step 2, the inner fin set (3) is connected to an inner wall of the heat transfer tube (1) fixing the outer fin set (2).

17. A method for using the compact gas-gas heat exchange tube as defined in claim 1, **characterized in that** it comprises steps: arranging at least one heat transfer tube (1) in a heat exchanger, wherein an in-tube fluid of the heat transfer tube (1) is input through an in-tube fluid inlet end of the heat exchanger, flows, along an inner side of the heat transfer tube, to an outlet end of the heat transfer tube (1), and then flows to an in-tube fluid outlet end of the heat exchanger; in a flow process, the in-tube fluid of the heat transfer tube (1) is subjected to a heat convection process with an inner fin set (3) and an inner side surface of the heat transfer tube (1); an out-tube fluid of the heat transfer tube (1) is input from an out-tube fluid inlet end of the heat exchanger, flows, along an outer side of the heat transfer tube (1), in a direction opposite that of the in-tube fluid of the heat transfer tube (1), and flows to an out-tube fluid outlet end of the heat exchanger; and in the flow process, the out-tube fluid of the heat transfer tube (1) is subjected to a heat transfer process with an outer side surface of the heat transfer tube (1) and the outer fin set (2), and a heat conduction process is generated among the outer fin set (2), the heat transfer tube (1) and the inner fin set (3).

18. A method for using the compact gas-gas heat exchange tube as defined in claim 2, **characterized in that** it comprises steps: arranging at least one heat transfer tube (1) in a heat exchanger, wherein an in-tube fluid of the heat transfer tube (1) is input through an in-tube fluid inlet end of the heat exchanger, flows, along an inner side of the heat transfer tube, to an outlet end of the heat transfer tube (1), and then flows to an in-tube fluid outlet end of the heat exchanger; in a flow process, the in-tube fluid of the heat transfer tube (1) is subjected to a heat convection process with an inner fin set (3), a positioning tube (4) and an inner side surface of the heat transfer tube (1); an out-tube fluid of the heat transfer tube (1) is input from an out-tube fluid inlet end of the heat exchanger, flows, along an outer side of the heat transfer tube (1), in a direction opposite that of the in-tube fluid of the heat transfer tube (1), and flows to an out-tube fluid outlet end of the heat exchanger; and in the flow process, the out-tube fluid of the heat transfer tube (1) is subjected to a heat transfer process with an outer side surface of the heat transfer tube (1) and the outer fin set (2), and a heat conduction process is generated among the outer fin set (2), the heat transfer tube (1), the inner fin set (3) and the positioning tube (4).

19. A method for using the compact gas-gas heat exchange tube as defined in claim 17 or 18, **characterized in that** it comprises steps: under the condition that a hole is provided on a fin of the inner fin set (3), making an in-tube fluid of a heat transfer tube (1) to flow through the hole on the fin of the inner fin set (3) and axially flow along the heat transfer tube (1); under the condition that a hole is provided on a fin of the outer fin set (2), making an out-tube fluid of a heat transfer tube (1) to flow through the hole on the fin of the outer fin set (2) and axially flow along the heat transfer tube (1); performing reverse flow heat exchange between the in-tube fluid and the out-tube fluid of the heat transfer tube (1); expanding, by the inner fin set (3), a heat exchange surface on an inner side of the heat transfer tube (1), forming a micro-channel to restrict the out-tube fluid from axially and reversely flowing along the heat transfer tube (1), and producing a turbulence effect and enhancing heat convection as well; and expanding, by the outer fin set (2), a heat exchange surface on an outer side of the heat transfer tube (1), forming a micro-channel to restrict the out-tube fluid from axially and reversely flowing along the heat transfer tube (1), and producing a turbulence effect and enhancing heat convection as well.

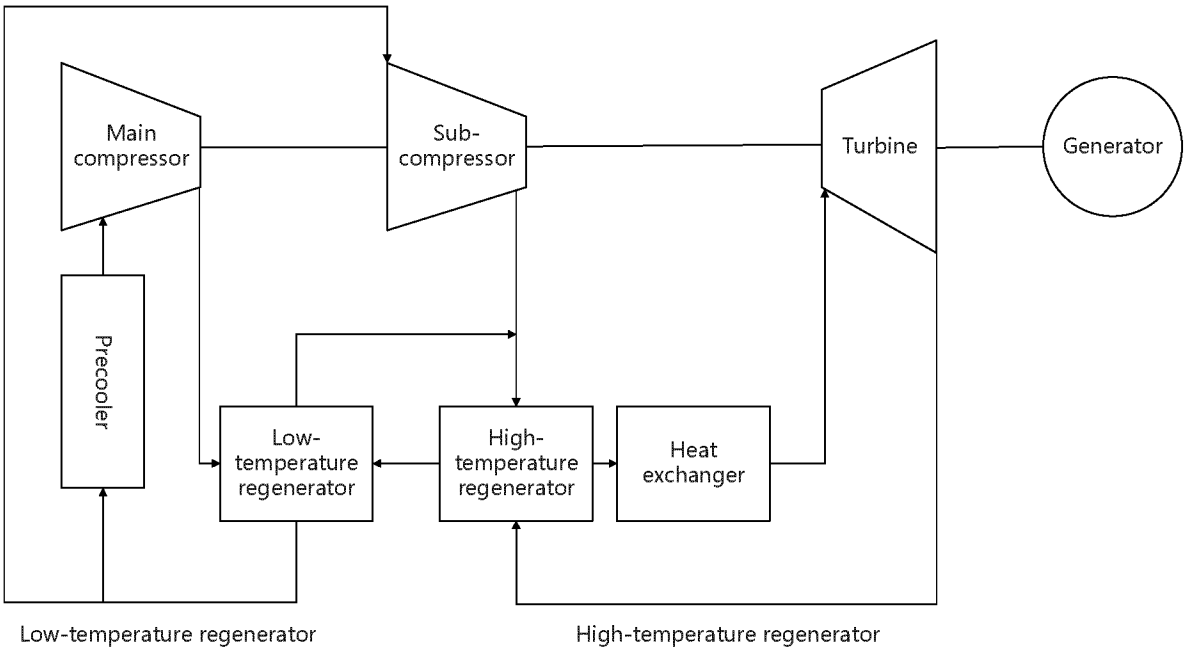

Fig. 1

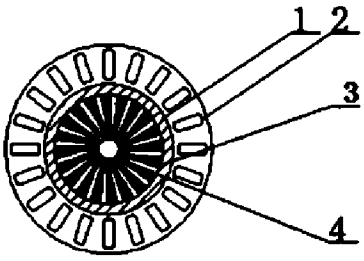

Fig. 2(a)

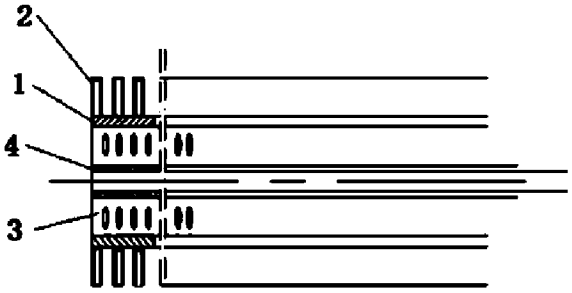

Fig. 2(b)

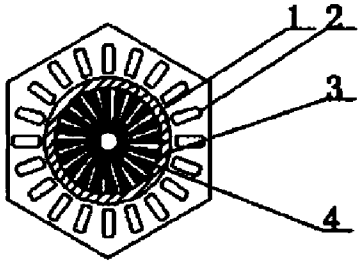

Fig. 3(a)

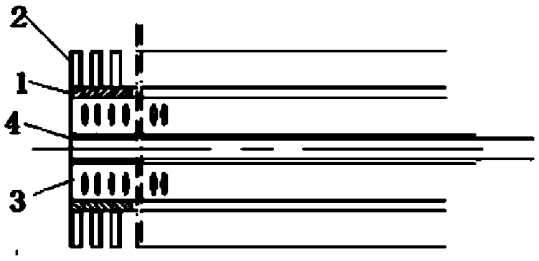

Fig. 3(b)

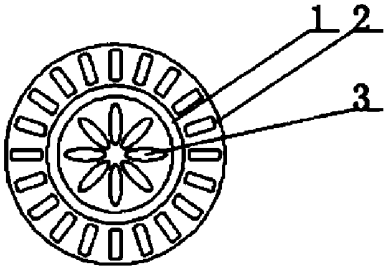

Fig. 4(b)

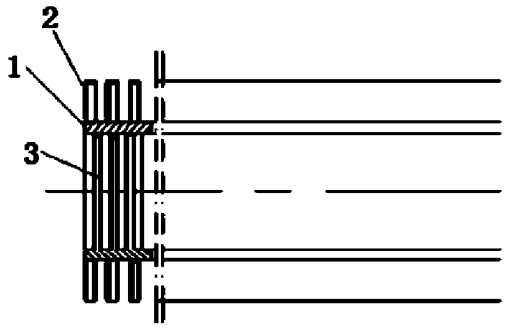

Fig. 4(b)

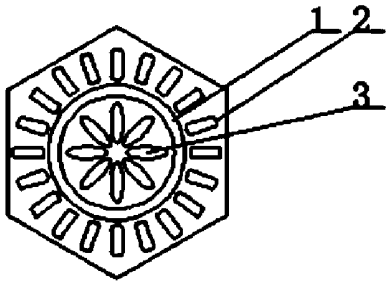

Fig. 5(a)

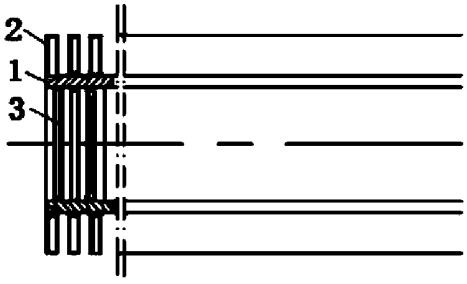

Fig. 5(b)

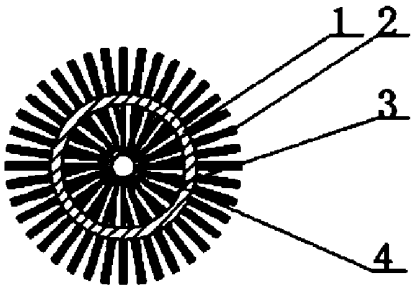

Fig. 6(a)

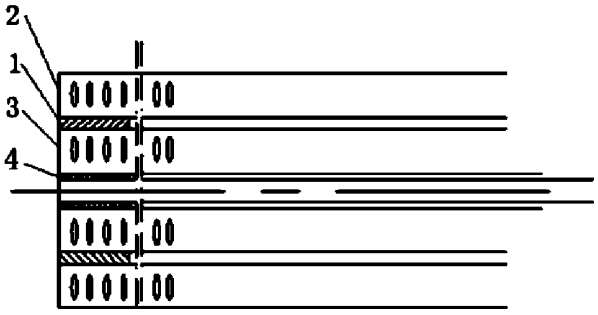

Fig. 6(b)

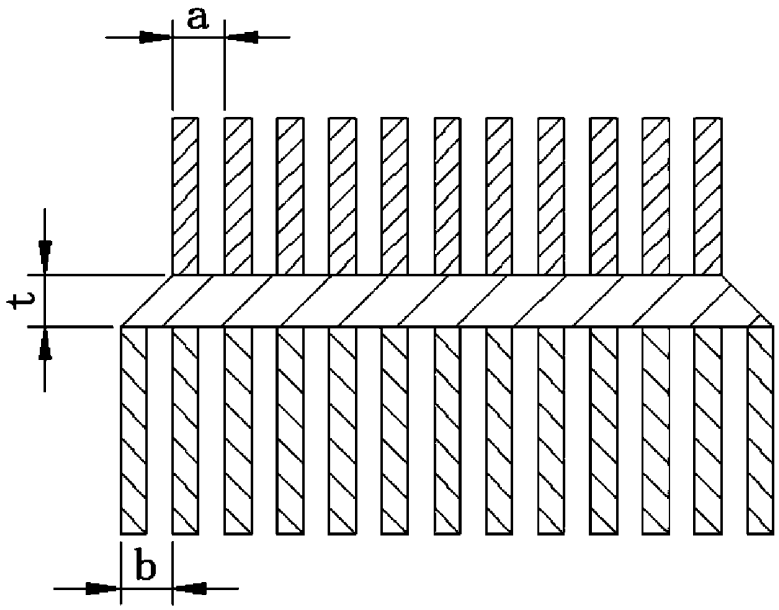

Fig. 7

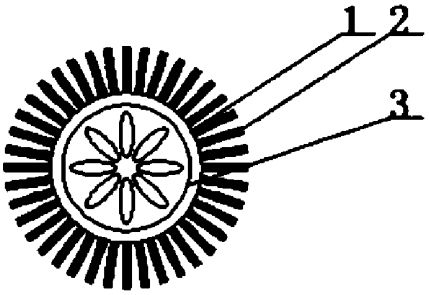

Fig. 8(a)

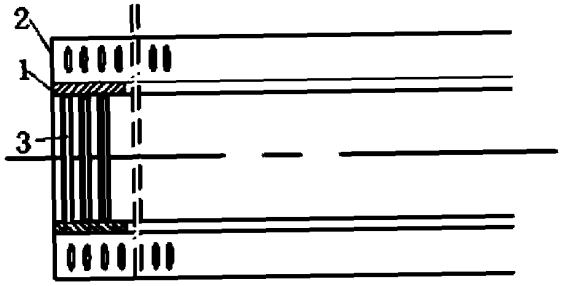

Fig. 8(b)

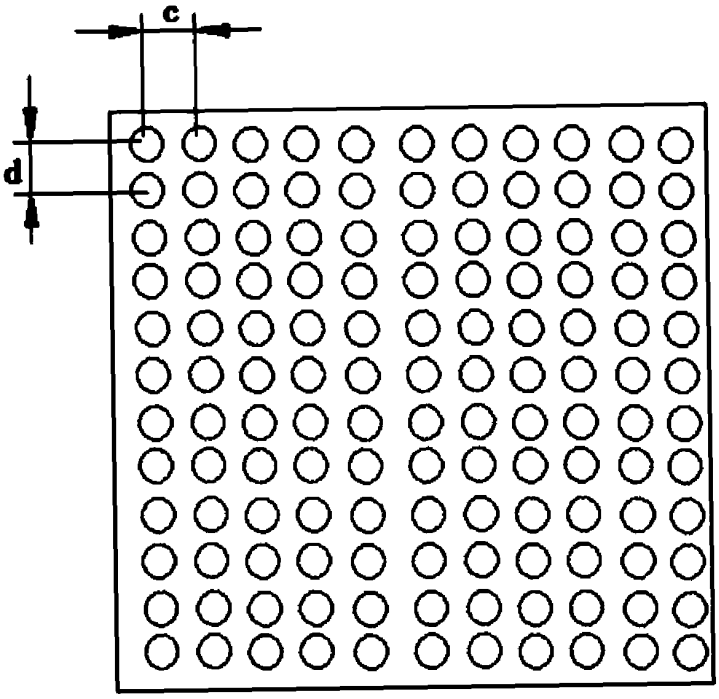

Fig. 9

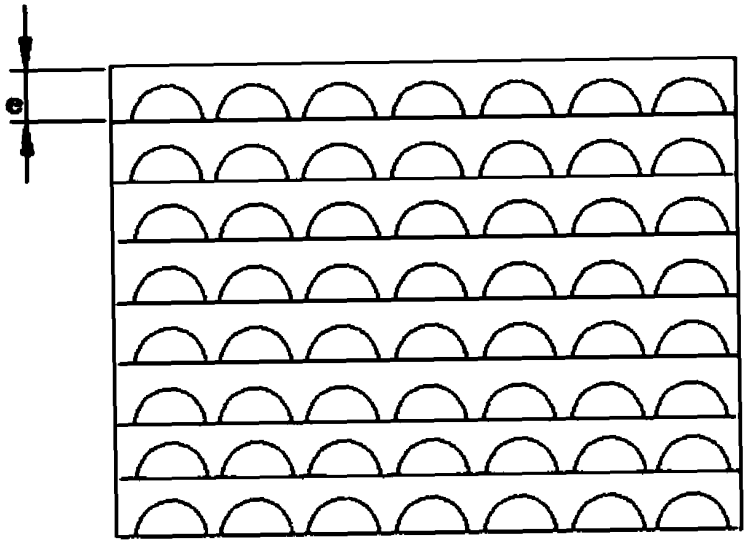

Fig. 10

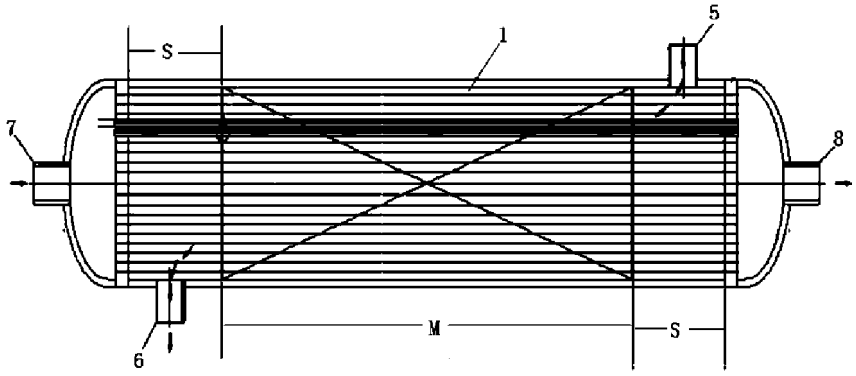

Fig. 11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2019/103749

A. CLASSIFICATION OF SUBJECT MATTER

F28F 1/42(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F28F1, F28D7

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

DWPI, EPODOC, CNABS, CNKI: 微通道, 孔, 洞, 缝, 开口, 百叶窗, microchannel, hole?, aperture?, opening?, slot?, baffle, louvre+, louver+

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
PX	CN 109059601 A (SHANGHAI POWER EQUIPMENT RESEARCH INSTITUTE CO., LTD.) 21 December 2018 (2018-12-21) claims	1-19
Y	CN 201434621 Y (XI'AN SHIYOU UNIVERSITY) 31 March 2010 (2010-03-31) description, page 4, line 1 to page 8, line 9, and figures 1-7	1-19
Y	CN 101067530 A (SAMSUNG KWANGIU ELECTRONICS CO., LTD.) 07 November 2007 (2007-11-07) description, page 6, line 6 to page 7, line 2, and figures 6-8	14-16
Y	CN 105605960 A (SHANDONG UNIVERSITY) 25 May 2016 (2016-05-25) description, paragraphs [0039]-[0052], and figures 1-5	1-19
A	CN 201344755 Y (HU, Qi) 11 November 2009 (2009-11-11) entire document	1-19
A	US 2012222845 A1 (KINDER, L.M. et al.) 06 September 2012 (2012-09-06) entire document	1-19

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

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"P" document published prior to the international filing date but later than the priority date claimed
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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 November 2019	**03 December 2019**
Name and mailing address of the ISA/CN **China National Intellectual Property Administration** **No. 6, Xitucheng Road, Jimenqiao Haidian District, Beijing 100088** **China** Facsimile No. **(86-10)62019451**	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2019/103749

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
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CN	201434621	Y	31 March 2010	None			
CN	101067530	A	07 November 2007	KR	100752635	B1	21 August 2007
				EP	1852668	A3	23 January 2013
				EP	1852668	A2	07 November 2007
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				CN	103403488	B	09 December 2015
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				CA	2828021	C	29 January 2019

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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