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(54) INDIRECT HEAT EXCHANGE DEVICE AND METHOD OF EXCHANGING HEAT

INDIREKTE WÄRMETAUSCHERVORRICHTUNG UND WÄRMETAUSCHVERFAHREN

DISPOSITIF D'ÉCHANGE THERMIQUE INDIRECT ET PROCÉDÉ D'ÉCHANGE THERMIQUE

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(73) Proprietor: **Shell Internationale Research
Maatschappij B.V.**
2596 HR The Hague (NL)

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(72) Inventor: **MULDER, Dominicus Fredericus
NL-1031 CM Amsterdam (NL)**

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Description

Field of the Invention

[0001] The present invention relates to an indirect heat exchange device comprising finned heat exchanger tubes and to a method of exchanging heat between a first fluid and a second fluid.

Background of the Invention

[0002] Finned heat exchanger tubes can be used in indirect heat exchange devices wherein a first fluid, which is passed through the interior of the finned tubes, can exchange heat with a second fluid outside the tubes.

[0003] For a variety of reasons, the geometric centroid of the cross-section of the envelope defined by the fins of a heat exchanger tube sometimes does not coincide with the axis of the tube. DE-A-1451143 describes an indirect heat exchange device of which the fins of the outer heat exchanger tubes contain additions to shade these outer fins from the sun or other sources of heat. GB-A-281,289 describes finned heat exchanger tubes of which the fins are arranged eccentric relatively to the centre of the tube, which tubes are arranged in layers having opposite eccentricity in order to force gases to take a sinuous path in order to increase the efficiency of the apparatus. US-A-4,002,198 describes a desublimator for isolating sublimation products comprising finned tubes intended to be alternately subjected from the inside to a heating medium and a coolant, the transverse fins of which tubes are arranged in rows staggered laterally in opposite directions by an amount corresponding to the whole spacing between adjacent fin edges to provide additional turbulence surfaces causing greater pressure drops. US-A-4,440,216 teaches to foreshorten the fins at the top of a heat exchanger tube in order for liquid to be more uniformly distributed over the tubes. The fins of liquid treated heat exchanger tubes have a relatively small surface area, i.e. the ratio of surface area of fins to surface area of the tube will be substantially less than 5. The eccentrically finned heat exchanger tube shown in Fig. 6 of NL-C-1019777 has a ratio of surface area of fins to surface area of the tube of substantially less than 5 as well.

[0004] Finned heat exchanger tubes may in particular be used in air-cooled heat exchanger devices, wherein the fluid outside the tubes is air.

[0005] Air-cooled heat exchangers can also be referred to as air coolers. Air coolers are described in Perry's Chemical Engineers' handbook, 7th edition, 1997, pages 11-47 to 11-52. Air coolers are for example used in refinery, petrochemical and chemical processes to cool or condense process fluids inside the tube with air outside the tube. Air coolers typically include a bundle of finned tubes, and a fan, which fan moves air across the tubes.

[0006] In air-cooled heat exchangers, the heat transfer from the fluid inside the tube to the tube itself is typically

much more efficient than the heat transfer between the fluid outside the tube (air) and the tube itself. The efficiency of heat transfer can for example be expressed by a so-called film coefficient as defined in Perry's, pages 5-12 to 5-19. In order to compensate for a difference in film coefficients, the external surface area of the heat exchanger tube is increased by means of fins, so that the product of film coefficient and surface area inside and outside of the heat exchanger tube is of the same order of magnitude.

[0007] Heat transfer due to free convection can be described by the following equation:

$$\frac{dQ}{dt} = h A (T_w - T_{\infty})$$

The rate dQ/dt of heat exchanged Q (also referred to as duty) with the surrounding fluid is proportional to the object's exposed area A , and the difference between the object temperature T_w and the fluid free-stream temperature T_{∞} . The constant of proportionality h is termed the convection heat-transfer coefficient, also referred to as film coefficient [units $W/(m^2.K)$].

[0008] The flow of fluid outside the tube is typically induced by a fan. The higher the air velocity, the higher the heat transfer coefficient and the higher the duty. However, the air velocity is often limited, such as by the maximum noise level of a fan, e.g. 80 dBa. For a given fan rotating at a certain speed, the air velocity across a bundle of finned tubes is determined by the static pressure drop (resistance) of the bundle. A higher air velocity will be achieved if the pressure drop (resistance) is lower.

[0009] Finned tubes are also employed in heaters or furnaces, such as fired heaters, for improving the heat transfer from the heating fluid surrounding the tubes to fluid that is flowing inside the tubes. It has been observed that coking of fluid inside heat exchanger tubes occurs preferentially at the upstream (upwind) side of the flow of fluid outside the tubes, for example in heaters for crude oil entering a crude distillation unit. Typically the heating fluid is combustion gas from the combustion of a fuel, rising upwardly in a heater.

[0010] Figure 6 of NL-A-1019777, which discloses the preamble of claim 1, is a schematic drawing of a finned heat exchange element and lacks information on how the fins are positioned vis-à-vis the flow of air.

[0011] It is desired to increase the efficiency of heat transfer in heat exchange devices comprising finned heat exchanger tubes.

Summary of the Invention

[0012] To this end there is provided an indirect air-cooled heat exchange device comprising heat exchanger tubes arranged in at least 2 layers each of which layers

comprises at least 2 heat exchanger tubes and a fan having a blow or suck direction across the heat exchanger tubes and defining an upstream side of the heat exchanger tubes wherein the heat exchanger tubes are eccentrically finned heat exchanger tubes having a ratio of surface area of the fins to surface area of the tube of at least 5, and in which device the heat exchanger tubes have for their position in the device, the same spacing both in magnitude and in direction between the axis of the tube and the geometrical centroid of the envelope defined by the fin and in which the geometric centroid of the cross-section of the envelope defined by the fins of the heat exchanger tubes is arranged upstream from the axis of the tubes.

[0013] Finned heat exchanger tubes have an axis and are provided with fins, the fins defining an envelope having a cross-section, wherein the cross-section of the envelope has a geometric centroid. In eccentrically finned heat exchangers, this geometric centroid is spaced apart from the axis of the tube.

[0014] The geometric centroid of an area, such as of the cross-section of the envelope of the fins, is similar to the center of mass of a body. Calculating the centroid is based on the geometrical shape of the area. Cartesian co-ordinates C_x , C_y of the geometric centroid can for example be determined by integration over the area A , $C_x = \int x \, dA/A$, $C_y = \int y \, dA/A$, $A = \int dA$.

[0015] The axis of the tube is the longitudinal axis of the interior of the tube.

[0016] Eccentricity is defined as the spacing, both in magnitude and direction, between the axis of the tube and the geometrical centroid of the envelope of the tube as positioned in the device. Finned heat exchanger tubes of similar eccentricity in the heat exchange device are finned tubes having an eccentricity which is the same both in magnitude and in direction for their position in the heat exchange device. The influence of the position in the device on the eccentricity of a tube is clear from Figures 1, 3 and 4 of GB-A-281,289 where the eccentricity of tubes in adjacent layers is opposite in direction due to the different position of tubes in adjacent layers.

[0017] In the indirect heat exchange device according to the present invention, most, preferably all, finned heat exchanger tubes of the device have a similar eccentricity. Preferably, the finned heat exchanger tubes of the device according to the present invention have the same eccentricity both in magnitude and direction.

[0018] It is preferred that the direction of the eccentricity of the heat exchanger tubes of the device is parallel, i.e. either the same or opposite in direction, to the direction in which fluid outside the tubes normally flows.

[0019] A substantial part of the static pressure drop due to a finned heat exchanger tube is caused by the fins. It has now been found that the effectiveness of finning with respect to heat transfer is higher at the upstream side of the tube than at the downstream side. In the description and in the claims, the upstream (also referred to as upwind) side is the side at which the fluid

flow direction outside the tubes is towards the finned tubes, and at the downstream (downwind) side the fluid flow outside the tubes is away from the tubes.

[0020] The different effectiveness can be observed for conventional concentric circular fins in that the temperature of the tips of such fins is lower on the upstream side than on the downstream side. The difference in temperature between the fin tip and the fluid surrounding the fin tip, hereinafter referred to as the differential temperature, is also higher for the fins at the upstream side of such conventional heat exchanger tubes. For this reason it is advantageous to arrange the finning eccentrically on the tubes, or in other words, to use non-concentric fins. It will be clear that the difference in effectiveness is more pronounced for heat exchanger tubes having a relatively high surface area, i.e. having a ratio of surface area of the fins to surface area of the tube of more than 5, more specifically at least 6, more specifically at least 7, more specifically at least 8, more specifically at least 9, and most specifically at least 10. It is especially preferred for the indirect heat exchange devices of the present invention to contain such high surface area heat exchanger tubes. The ratio of surface area of the fins to surface area of the tube preferably is at most 25. The surface area of the fins is the surface area of the fins to be in contact with the fluid outside the tube while the surface area of the tube is the surface area of the tube in contact with the fluid inside the tube.

[0021] A particular phenomenon in heat transfer by finned tubes is recirculation, i.e. eddies formed in the fluid at the downstream side, which hamper efficient heat transfer. This effect is also minimized by having the larger part of the fin surface at the upstream side. By proper design for a particular application it can be achieved that the upstream and downstream differential temperatures at the tips of the fins of the heat exchanger tubes are substantially equal.

[0022] The fin can have any suitable shape such as circular, elliptical, oval, polygonal, or egg-shaped (i.e. roughly oval with somewhat different radii at the tips; the larger radius can suitably be arranged at the downstream side). An elliptical shape has shown good results.

[0023] Because the heat transfer is optimised, less finning is required to achieve the same duty. Moreover, if less finning is used, the static pressure drop over a bundle will reduce so that the maximum air velocity for a given fan capacity will increase, so that the overall duty can be increased.

[0024] The indirect heat exchange device according to the present invention comprises at least 2 layers, preferably at least 3 layers, more preferably at least 4 layers of heat exchanger tubes. Preferably, the number of layers is at most 10, more preferably at most 9. Further, each layer comprises at least 2, more preferably at least 3, more preferably at least 4 heat exchanger tubes. The number of layers and the number of tubes is the number of times the tube is present independent from whether the tubes are connected to each other such as via a tube

bend.

[0025] The heat exchanger tubes in adjacent layers are preferably arranged staggered with respect to each other while the tubes in the device still have similar eccentricity.

[0026] The heat exchange device according to the present invention can further comprise a fan having a blow or suck direction across the heat exchanger tubes and defining an upstream side of the heat exchanger tubes, and wherein the geometric centroid of the cross-section of the envelope defined by the fins is arranged upstream from the axis of the tube.

[0027] The problem of preferential coking in a heater can also be solved with the help of the heat exchange device according to the present invention. According to the present invention, the geometric centroid of the cross-section of the envelope defined by the fins preferably is arranged downstream from the axis of the tubes with respect to the direction of heating fluid flow across the heat exchange device (typically the upper side). Accordingly, in a particular aspect the invention provides an indirect heat exchange device arranged in a heater having flow direction of heating fluid across the heat exchange device and defining a downstream side of the heat exchanger tubes of the device, and wherein the geometric centroid of cross-section of the envelope defined by the fins is arranged downstream from the axis of the tubes. In this way a more equal heat transfer around the circumference of the tube is achieved, so that temperature differences at the inner wall between the upstream and downstream sides are minimized. This will suppress preferential coking at the upstream side within the tubes.

[0028] In the description and in the claims the expression "the geometric centroid of the cross-section of the envelope defined by the fins is arranged upstream (or downstream) from the axis of the tube" refers to a position of the geometric centroid in a plane parallel to a plane through the tube axis and perpendicular to the direction of the flow of fluid outside the tubes, and which plane is more upstream (or more downstream) than the plane through the tube axis, respectively. The geometric centroid is in an upstream position along the direction of fluid flow outside the tubes with respect to the axis of the tube.

[0029] The invention also provides the use of the indirect heat exchange device according to the invention for exchanging heat between a first fluid inside the tubes and a second fluid outside the tubes. Accordingly, the invention provides a method of exchanging heat according to claim 4.

[0030] Preferably, the upstream and downstream differential temperatures, as defined above and with respect to the flow of fluid outside the tubes, at the tip of the fins of the heat exchanger tubes are substantially equal during use in the method according to the invention.

[0031] Heat exchanger tubes for use in the device according to the present invention can be manufactured in many different ways. A suitable method of manufacturing comprises

- providing a tube having an outer surface and a circumference;
- providing an elongated strip of fin material having a length direction, the strip having a straight side along its length direction, and a side opposite the straight side, wherein the width of the strip varies along the length direction defining maxima and minima, wherein the maxima are spaced apart in length direction substantially by the circumference of the tube;
- spirally winding the strip around the tube so that the straight side is attached to the outer surface of the tube.

[0032] Using this method a finned heat exchanger tube can be obtained, which has an eccentric envelope with respect to the axis of the tube, wherein the geometric centroid of cross-sections of the envelope extends a line parallel to the longitudinal axis of the tube. The elongated strip can be efficiently manufactured by cutting from an elongated strip with parallel straight sides, so that two elongated strips are obtained.

Brief description of the Drawings

[0033] The invention will now be described in more detail and with reference to the accompanying drawings, wherein

Figure 1 shows schematically a conventional finned heat exchanger tube in perspective view;

Figure 2 shows schematically the conventional finned heat exchanger tube of Figure 1 in transverse cross-section;

Figure 3 shows schematically a first embodiment of a finned heat exchanger tube for use in a device according to the invention in transverse cross-section;

Figure 4 shows schematically a second embodiment of a finned heat exchanger tube for use in a device according to the invention in transverse cross-section;

Figure 5 shows schematically an indirect heat exchange device and a fan according to the invention.

[0034] Where the same reference numerals are used in different Figures, they refer to the same or similar objects.

Detailed Description of the Invention

[0035] Reference is made to Figure 1, showing schematically a conventional finned heat exchanger tube 1. The tube is provided with fins 3 of circular cross-section. The fins are obtained by helically winding a strip of metal around the inner tube 5. The fins define an envelope 7 having a circular cross-section 8. The geometric centroid of the circle 8 is in the centre 9, which coincides in this

case with the longitudinal axis 10 of the tube 1. The conventional finned heat exchanger tube 1 is shown in transverse cross-section in Figure 2.

[0036] Reference is now made to Figure 3, showing schematically a finned heat exchanger tube 21 for use in a device according to the invention. The tube is provided with fins 23 defining an envelope 24 of elliptical cross-section 25, eccentrically with respect to the longitudinal axis 30 of the tube 21. I.e., the geometric centroid 31, which is at the cross section of the major and minor axes 32,33 of the ellipse, is spaced apart from the axis 30.

[0037] Figure 4 shows schematically another embodiment of a finned heat exchanger tube 41 for use in a device according to the invention. Here the fins 43 define an envelope 44 of circular cross section 45. The centre 46 of the circle 45 is spaced apart from the longitudinal axis 50 of the tube 41.

[0038] Reference is now made to Figure 5 showing schematically a device 51 according to the invention comprising eccentrically finned heat exchanger tubes 53, in an assembly 54 with a fan 55, for example to form an air-cooled heat exchanger. The device in this example comprises 4 layers of tubes when viewed along the blow direction 58 of the fan 55, each of which layer comprises 3 or 4 heat exchanger tubes. Each tube has an upstream side 60 and a downstream side 61, wherein the upstream side is closer to the fan 55 than the downstream side in the case of a fan that blows. The finned tubes 53 are eccentric elliptical as discussed with reference to Figure 3.

[0039] During operation of the assembly 54, a first fluid is passed through the interior 62 of the tubes 53, and the fan blows second fluid (e.g. air) across the tubes along the blow direction 58, so as to exchange heat between the first and second fluids, e.g. to cool the first fluid against air.

[0040] The elliptical fins are non-concentrically arranged such that the geometric centroid of their envelope is below the axis of the tubes in Figure 5, at the side of the blowing fan.

[0041] Computational Fluid Dynamics calculations have been performed, in order to compare the heat transfer duty and pressure drop of a four layer bank of finned heat exchanger tubes according to the invention with an analogous arrangement of conventional circular finned tubes. The calculations were performed using a so-called EFD. Lab software package.

[0042] The model assumes copper tube cores with aluminium fins. The tube core has a fixed temperature of 100 °C. The ambient temperature of the air is 30 °C. The tubes are in cross flow, with an ambient air velocity of 4 m/s. The following parameters were used in the calculations.

Finned tube dimensions (all examples):

Bare inner tube outer diameter: 25.4 mm
Fin thickness: 0.4 mm
Fin pitch (10 fins/inch): 2.54 mm

Fin spacing: 2.14 mm
Ratio of surface area of fins to surface area of tube: 20

5 Bank dimensions:

Tube pitch: 63 mm
Stagger angle: 60 degrees
4 layers each comprising several tubes

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Example 1

[0043] The device according to the invention comprised ellipsoid and eccentrically finned tubes.

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Major diameter: 74.4 mm
Minor diameter: 42.98 mm
Minimum fin height: 10 mm
Maximum fin height: 39 mm
Magnitude of eccentricity: 15 mm

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Comparative Example 2:

[0044] The device not according to the invention comprised conventional concentric circular finned tubes.

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Fin height: 15.88 mm
Outer diameter of fin envelope: 57.15 mm

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[0045] In Example 1, a duty of 1366.9 W per meter length of the finned tube was obtained, at a pressure drop of 101.5 Pa. In the Comparative Example 2, the duty was somewhat higher, 1505.5 W/m, but at a much higher pressure drop namely 132.0 Pa. The ratio of duty to pressure drop was 18% higher in the Example 1 according to the invention.

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[0046] The embodiment of a heater wherein preferential coking is to be suppressed would be similar to Figure 5, but instead of the fan a burner would be arranged, and the elliptical fins would be arranged with the geometric centroid of their envelope above the axis of the tubes in Figure 5, away from the burner.

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45 **Claims**

1. Indirect air-cooled heat exchange device comprising heat exchanger tubes arranged in at least 2 layers each of which layers comprises at least 2 heat exchanger tubes and a fan having a blow or suck direction across the heat exchanger tubes and defining an upstream side of the heat exchanger tubes wherein the heat exchanger tubes are eccentrically finned heat exchanger tubes
, **characterised in that** the heat exchanger tubes have for their position in the device the same spacing, both in magnitude and in direction, between the axis of the tube and the geometrical centroid of the

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envelope defined by the fin, the heat exchanger tubes having a ratio of surface area of the fins to surface area of the tube of at least 5 and that the geometric centroid of the cross-section of the envelope defined by the fins of the heat exchanger tubes is arranged upstream from the axis of the tubes.

2. Indirect air-cooled heat exchange device according to claim 1, **characterised in that** the ratio of surface area of the fins to surface area of the tube is at least 7.
3. Indirect air-cooled heat exchange device according to claim 1 or 2, **characterised in that** the direction of the eccentricity is parallel to the direction in which fluid outside the tube normally flows.
4. A method of cooling fluid with air, the method comprising

- providing a indirect heat exchange device;
- passing fluid through the heat exchanger tubes of the device;
- passing air along a flow direction across the indirect heat exchange device, wherein the eccentricity of the heat exchanger tubes is parallel to the flow direction of air,

characterised in that the heat exchange device is according to any one of claims 1-3 having the geometric centroid of the fins of each of the heat exchanger tubes arranged upstream from the axis of the tubes.

5. The method according to claim 4, **characterised in that** the upstream and downstream differential temperatures at the tip of the fins of the heat exchanger tubes are substantially equal.

Patentansprüche

1. Indirekt luftgekühlte Wärmeaustauschvorrichtung mit Wärmeaustauscherrohren, die in zumindest zwei Lagen angeordnet sind, wobei jede Lage zumindest zwei Wärmeaustauscherrohre und ein Gebläse mit einer Blasoder Saugrichtung über die Wärmeaustauscherrohre aufweist, das eine stromaufwärtige Seite der Wärmeaustauscherrohre definiert, wobei die Wärmeaustauscherrohre mit exzentrischen Lamellen versehene Wärmeaustauscherrohre sind, **dadurch gekennzeichnet, daß** die Wärmeaustauscherrohre für ihre Position in der Vorrichtung den gleichen Abstand, sowohl hinsichtlich Größe als auch Richtung, zwischen der Achse des Rohres und dem geometrischen Schwerpunkt der durch die Lamellen definierten Hülle aufweisen, wobei das Verhältnis der Oberflächenzone der Lamellen zur Oberflächenzone des Rohres zumindest 5 beträgt, und

wobei der geometrische Schwerpunkt des Querschnittes der Hülle, der durch die Lamellen der Wärmeaustauscherrohre definiert ist, stromaufwärts der Achse der Rohre vorgesehen ist.

2. Indirekt luftgekühlte Wärmeaustauschvorrichtung nach Anspruch 1, **dadurch gekennzeichnet, daß** das Verhältnis der Oberflächenzone der Lamellen zur Oberflächenzone des Rohres zumindest 7 beträgt.
3. Indirekt luftgekühlte Wärmeaustauschvorrichtung nach Anspruch 1 oder 2, **dadurch gekennzeichnet, daß** die Richtung der Exzentrizität parallel zu jener Richtung verläuft, in welcher das Fluid außerhalb des Rohres normalerweise strömt.
4. Verfahren zum Kühlen von Fluid mit Luft, wobei das Verfahren umfaßt

- Vorsehen einer indirekten Wärmeaustauschvorrichtung;
- Leiten von Fluid durch die Wärmeaustauscherrohre der Vorrichtung;
- Leiten von Luft entlang einer Strömungsrichtung über die indirekte Wärmeaustauschvorrichtung, wobei die Exzentrizität der Wärmeaustauscherrohre parallel zur Strömungsrichtung der Luft verläuft,

dadurch gekennzeichnet, daß die Wärmeaustauschvorrichtung gemäß einem der Ansprüche 1-3 ausgebildet ist, wobei der geometrische Schwerpunkt der Lamellen jedes der Wärmeaustauscherrohre stromaufwärts der Achse der Rohre vorgesehen ist.

5. Verfahren nach Anspruch 4, **dadurch gekennzeichnet, daß** die stromaufwärtigen und stromabwärtigen Differentialtemperaturen an der Spitze der Lamellen der Wärmeaustauscherrohre im wesentlichen gleich sind.

Revendications

1. Dispositif échangeur de chaleur indirect refroidi à l'air, comprenant des tubes d'échange de chaleur aménagés en au moins deux couches, dont chacune comprend au moins deux tubes d'échange de chaleur et un ventilateur ayant un sens de soufflage et un sens d'aspiration en travers des tubes d'échange de chaleur et définissant un côté amont des tubes d'échange de chaleur, dans lequel les tubes d'échange de chaleur sont des tubes d'échange de chaleur à ailettes excentriques, **caractérisé en ce que** les tubes d'échange de chaleur ont, pour leur position dans le dispositif, le même espacement à la fois en grandeur et en direction, entre l'axe du tube

et le centroïde géométrique de l'enveloppe définie par l'ailette, les tubes d'échange de chaleur ayant un rapport de surface des ailettes à la surface du tube d'au moins 5, et **en ce que** le centroïde géométrique de la section transversale de l'enveloppe définie par les ailettes des tubes d'échange de chaleur est aménagé en amont de l'axe des tubes. 5

2. Dispositif échangeur de chaleur indirect refroidi à l'air selon la revendication 1, **caractérisé en ce que** le rapport de la surface des ailettes à la surface du tube est d'au moins 7. 10

3. Dispositif échangeur de chaleur indirect refroidi à l'air selon la revendication 1 ou 2, **caractérisé en ce que** la direction de l'excentricité est parallèle à la direction dans laquelle le fluide extérieur au tube s'écoule normalement. 15

4. Procédé de refroidissement de fluide avec de l'air, le procédé consistant à : 20

- mettre en oeuvre un dispositif échangeur de chaleur indirect ;
- faire passer un fluide à travers les tubes d'échange de chaleur du dispositif ; 25
- faire passer de l'air dans une direction d'écoulement transversale au dispositif d'échangeur de chaleur indirect, l'excentricité des tubes d'échange de chaleur étant parallèle à la direction d'écoulement de l'air, **caractérisé en ce que** le dispositif d'échange de chaleur est conforme à l'une quelconque des revendications 1 à 3 ayant le centroïde géométrique des ailettes de chacun des tubes d'échange de chaleur aménagé en amont de l'axe des tubes. 30 35

5. Procédé selon la revendication 4, **caractérisé en ce que** les températures différentielles amont et aval à la pointe des ailettes des tubes d'échange de chaleur sont sensiblement égales. 40

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Fig.1

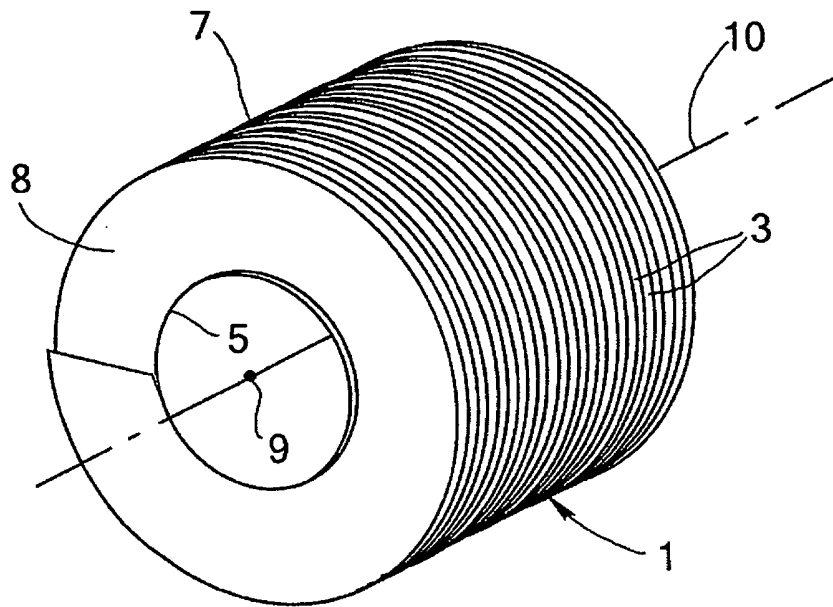


Fig.2

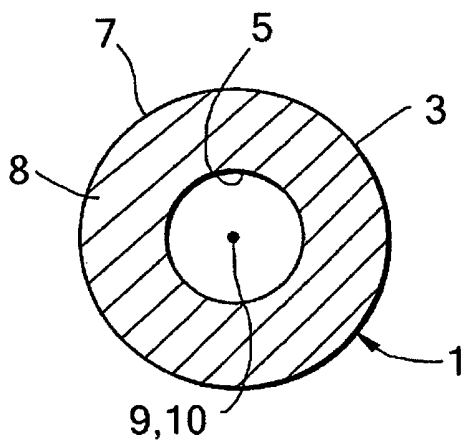


Fig.3

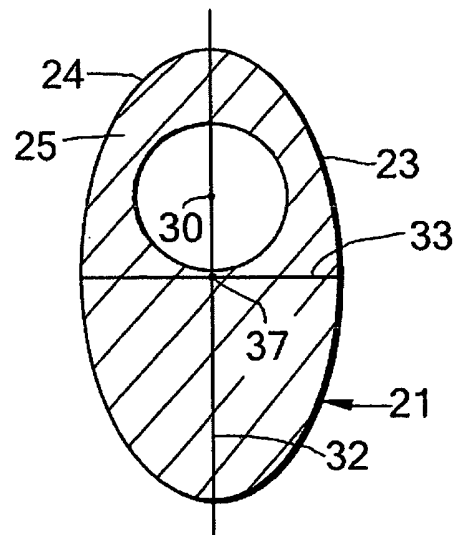


Fig.4

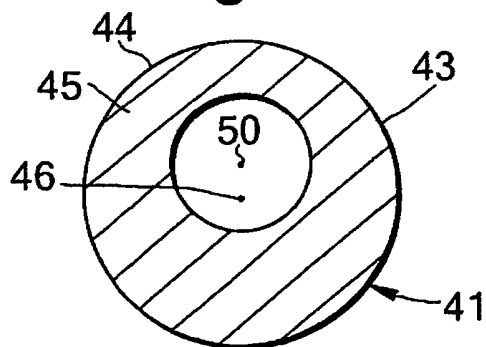
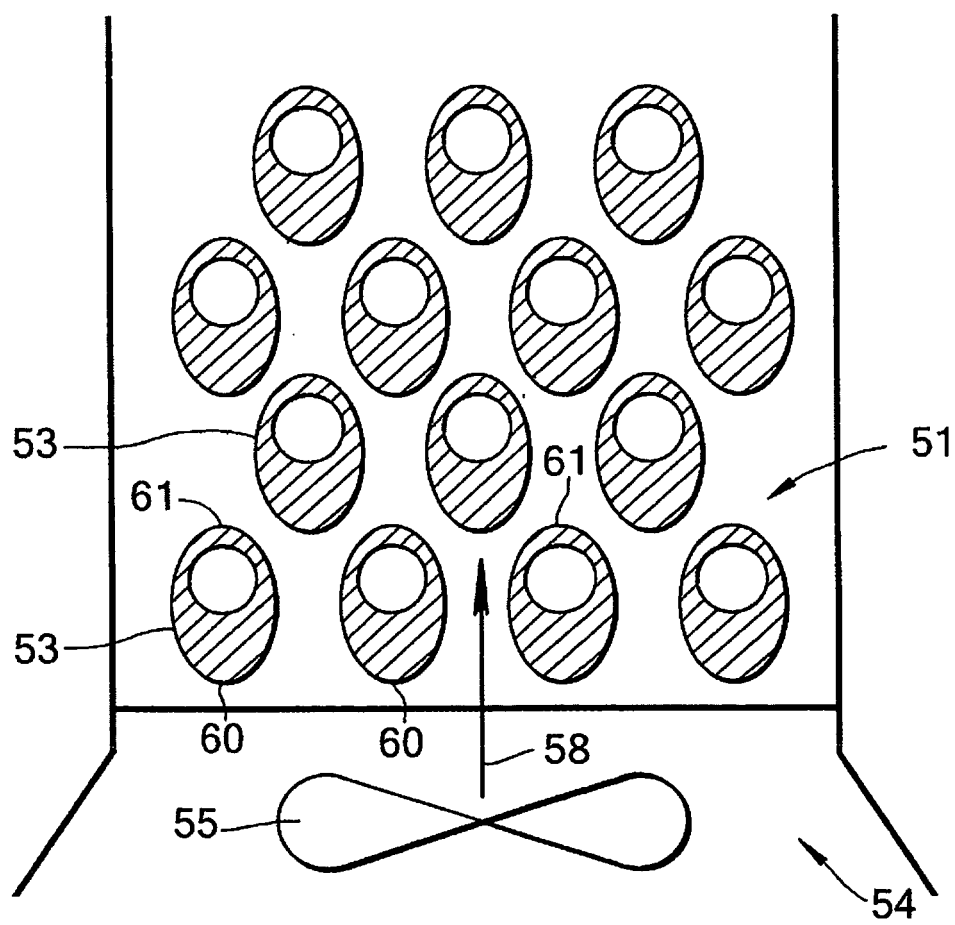


Fig.5



REFERENCES CITED IN THE DESCRIPTION

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