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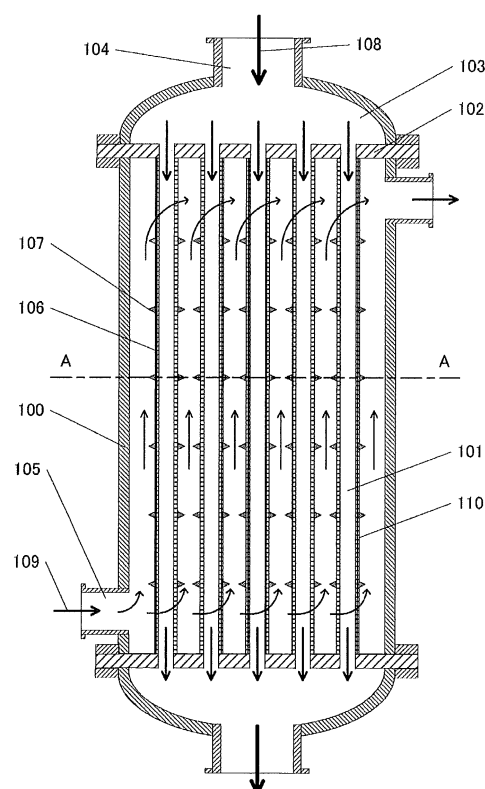
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(54) **Heat-transfer device**

(57) The invention includes a micro porous layer (110) and a plurality of heat-transfer enhancing structures (107) on a surface of the heat transfer tube (101) in contact with the cold fluid. The heat-transfer enhancing structures (107) have a height H that satisfies a relationship to a flow characteristic length D of $0.05 > H/D \geq 0.01$, and a relationship to an installation clearance L between the heat-transfer enhancing structures in a flow direction of $40 < L/H \leq 300$.

FIG. 1



Description**BACKGROUND OF THE INVENTION**

1. Field of the Invention

[0001] The present invention relates to a heat-transfer device.

2. Description of the Related Art

[0002] Heat exchangers, which allow two fluids at different temperatures to perform heat exchange, and heaters and coolers of fluids often use convective heat transfer, which is a form of heat transfer that uses heat transportation by flow. In the convective heat transfer, thermal energy is transferred from a heating or cooling surface through a heat conduction layer, a transition layer, and a convection layer to a fluid. The heat conduction layer is a fluid layer formed in a very thin region on the heating or cooling surface. In this layer, heat conduction due to fluid molecular diffusion is dominant rather than the heat transportation by flow. The heat conduction layer has a thickness determined by the Reynolds number Re , which is a dimensionless number representing the ratio of inertial forces to viscous forces in a flow, and the Prandtl number Pr , which is a dimensionless number representing the ratio of viscosity diffusion to thermal diffusion. As the Reynolds number and the Prandtl number increase, the thickness of the heat conduction layer decreases. With flow velocity represented by U [m/s], a flow characteristic length by D [m], and a fluid coefficient of kinematic viscosity by ν [m²/s], the Reynolds number is defined by an expression below.

$$Re = (UD) / \nu \quad \dots\dots\dots (1)$$

With fluid thermal diffusivity represented by α [m²/s], the Prandtl number is defined by an expression below.

$$Pr = \nu / \alpha \quad \dots\dots\dots (2)$$

[0003] A conventional technique to improve heat-transfer performance for a heat-transfer device, such as a heat exchanger, is described in JP 2005-69520 A. In this conventional technique, a plate-like copper is used as a heat transfer surface. This surface is chemically etched with an acid or alkaline mixed with carbon nanotubes, copper oxide nanoparticles, or aluminum oxide nanoparticles to form a nano-particle porous layer thereon.

SUMMARY OF THE INVENTION

[0004] However, the heat transfer enhancement technique described in JP 2005-69520 A uses the activation of molecular motion in a heat conduction layer on the nano-particle porous layer, and thus, the thickness of the heat conduction layer needs to be not more than a value several tens of times of the thickness of the nano-particle porous layer in order to obtain effect of the heat transfer enhancement up to a certain point. This technique, thus, suffers difficulty in obtaining the heat-transfer enhancement effect of the nano-particle porous layer sufficiently due to an increased thickness of the heat conduction layer in a field where the Reynolds number is small, in other words, in a low-velocity flow field (for example, in a range of 0 to 10 m/s).

[0005] An object of the invention is to obtain heat-transfer enhancement effect of a micro porous layer sufficiently even at low flow velocities.

[0006] The invention includes a micro porous layer and a plurality of heat-transfer enhancing structures on a surface of the heat transfer tube, the surface being in contact with the cold fluid.

[0007] The invention allows the heat-transfer enhancement effect of the micro porous layer to be obtained sufficiently even at low flow velocities.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008]

Fig. 1 is a structure diagram of a shell and tube heat exchanger according to a first embodiment;

Fig. 2 is a sectional view taken along line A-A of Fig. 1;

Fig. 3 is an enlarged sectional view of a heat transfer tube outer surface in Fig. 1;

Fig. 4 is a structure diagram of a shell and tube heat exchanger according to a second embodiment;

Fig. 5 is a sectional view taken along line A-A of Fig. 4;

Fig. 6 is a graph of test data demonstrating the relationship of H/D to a heat-transfer enhancement ratio;

Fig. 7 is a graph of test data demonstrating the relationship of L/H to the heat-transfer enhancement ratio; and

Fig. 8 is a graph of a component test result for a heat-transfer performance improvement ratio.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0009] The invention relates to a heat-transfer device usable as a heat exchanger, which allows two fluids at different temperatures to perform heat exchange, and as a heater or a cooler of a fluid. Some embodiments of the invention will now be described with reference to the drawings.

First embodiment

[0010] A first embodiment of the invention is a shell and tube heat exchanger with the heat-transfer device applied. This embodiment is capable of improving heat-transfer performance even under conditions of low flow velocities of a fluid used for heat exchange, in comparison with a conventional shell and tube heat exchanger.

[0011] Fig. 1 is a structure diagram of the shell and tube heat exchanger according to the embodiment. A shell 100, which is circular or polygonal, is provided on both sides with tube plates 102 for supporting heat transfer tubes 101. The tube plates 102 each have a large number of holes arranged therein in a zigzag manner to allow the passage of the heat transfer tubes 101. The heat transfer tubes 101 pass through these tube holes to be fixed to the tube plates 102 at both sides. The heat transfer tubes 101 are made with a metal having high thermal conductivity, such as aluminum and copper. The heat transfer tubes 101 may be made with SUS. A vapor 108, which is a hot fluid, flows through a nozzle 104, located at an upper portion of the heat exchanger, into the heat exchanger. The vapor 108 flows through a liquid chamber 103, located at an upper portion of the heat exchanger, into the heat transfer tubes 101 to flow downward therethrough. The vapor 108 condenses into a compressed liquid by heat exchange with a cold fluid 109 through the walls of the heat transfer tubes. The compressed liquid flows through a liquid chamber, located at a lower portion of the heat exchanger, and through a nozzle, located at a lower portion of the heat exchanger, to the outside of the heat exchanger. Air 109, which is the cold fluid, flows through a nozzle 105, provided at a side of a lower portion of the heat exchanger, into the heat exchanger. As the air 109 rises outside the heat transfer tubes 101, the heat exchange is performed with the vapor 108, which is the hot fluid, through the walls of the heat transfer tubes. The air, having finished with the heat exchange, flows through a nozzle, provided at a side of an upper portion of the heat exchanger, to the outside of the heat exchanger.

[0012] There is a demand for enhanced convective heat transfer outside the heat transfer tubes because the convective heat transfer coefficient by the air flow outside the heat transfer tubes 101 is several hundredths of the condensation heat transfer coefficient by condensation heat transfer using the phase change of the vapor inside the heat transfer tubes 101. A micro porous layer 110 is formed on an outer surface 106 of each of the heat transfer tubes 101 to enhance the convective heat transfer outside the heat transfer tubes in the embodiment. The micro porous layer 110 is formed on the heat transfer tube outer surface 106 through a method described in JP 2005-69520 A before the heat transfer tubes 101 are welded onto the tube plates 102. The heat transfer tube outer surface 106 is chemically etched with an acid or alkali mixed with carbon nanotubes, copper oxide nanoparticles, or aluminum oxide nanoparticles to form a nanoparticle porous layer on the heat transfer tube outer surface 106. A porous layer formed through an anodic oxidation method may be used as the micro porous layer 110 in place of the nano-particle porous layer. In a well-known anodic oxidation method, the heat transfer surface is machined for smoothing. Then, dc or ac voltage is applied to the heat transfer tubes 101 serving as the anode with a 3 to 8% oxalate solution serving as an electrolytic solution for electrochemical reaction on the outer surfaces 106 of the heat transfer tubes 101. The metal (for example, aluminum) of the outer surfaces of the heat transfer tubes dissolved by the electrochemical reaction bonds with oxygen in the electrolytic solution to form through metal oxidation a porous anodic oxide film, or a porous layer, on each of the heat transfer tube outer surfaces 106.

[0013] The micro porous layer 110 of each of the heat transfer tube outer surfaces 106 needs to have asperities thereon with a height h not more than several tens of times of the mean free path (the average distance travelled by a molecule before collision with another molecule) of molecules in order to activate air molecular motion for enhanced heat conduction. With gas pressure represented by P [Pa], temperature by T [K], and molecule diameter by d

[0014] [m], the mean free path λ is calculated with an expression below.

$$\lambda = 3.11 \times 10^{-24} T / (Pd^2) \dots\dots\dots (3)$$

[0015] The mean free path in the air at atmospheric pressure and 20°C is approximately 0.06 μm. The height h of the asperities on the micro porous layer 110 on each of the heat transfer tube outer surfaces 106 is desirably not more than 10 μm in order to activate the air molecular motion. The micro porous layer 110 may be formed in any other method in place of the method described above as long as the height of the asperities is not more than 10 μm.

[0016] A plurality of heat-transfer enhancing structures 107 is installed on each of the heat transfer tube outer surfaces 106 to further improve the heat transfer enhancement by the micro porous layer 110. The heat-transfer enhancing structures 107 are formed with a metal material, such as aluminum, copper, and SUS. Other materials, such as a heat resistant rubber and a heat resistant resin, may be used to improve manufacturability. The heat-transfer enhancing structures 107 may each have a section of any form, such as triangular, rectangular, and circular sections, as long as its height can be defined. Fig. 2 is a sectional view taken along line A-A of Fig. 1. The heat-transfer enhancing structures 107 according to the embodiment are ring-shaped protrusions around each of the heat transfer tubes 101.

[0017] Fig. 3 is an enlarged sectional view of one of the heat transfer tube outer surfaces for describing the relationship between the heat transfer tube outer surface 106, corresponding one of the micro porous layers 110, and the heat-transfer enhancing structures 107 of the shell and tube heat exchanger according to the embodiment. A nano-particle porous layer per the method described in JP 2005-69520 A, a porous layer per the anodic oxidation method, or the micro porous layer 110 per any other method is formed on the heat transfer tube outer surface 106. The height h of the asperities on the micro porous layer 110 is not more than 10 μm. The plurality of heat-transfer enhancing structures 107 is installed on the micro porous layer 110 in such a manner that can cause turbulence of the air flow. Specifically, the heat-transfer enhancing structures 107 are provided substantially perpendicular to the direction of the air flow. Without the heat-transfer enhancing structures 107, the thickness of the heat conduction layer increases at low air flow velocities, preventing the micro porous layer 110 from producing the heat-transfer enhancement effect sufficiently as described above. Hence, the heat-transfer enhancing structures 107 are installed on the micro porous layer 110 to reduce the thickness of the heat conduction layer at low flow velocities, thereby producing the heat-transfer enhancement effect of the micro porous layer 110 sufficiently. The heat-transfer enhancing structures 107 cause separation of the flow, increasing the turbulence 111 of the air flow downstream of the heat-transfer enhancing structures 107. The air flow turbulence causes flow disturbance near the heat transfer surface, reducing the thickness of the heat conduction layer. To allow the heat-transfer enhancing structures 107 to produce sufficient turbulence, the heat-transfer enhancing structures 107 need to have a height sufficiently greater than the thickness of the heat conduction layer of the flow. Fig. 6 is a graph of a test result with parameters of a characteristic length D [m] of the flow and the height H [m] of the heat-transfer enhancing structures 107. A heat-transfer enhancement ratio is a ratio to a value with H/D ≈ 0.05. This test result demonstrates that a high heat-transfer enhancement ratio is obtained under a condition of H/D ≥ 0.01, and thus the heat-transfer enhancing structures 107 desirably satisfy the relationship of H/D ≥ 0.01. The characteristic length D of the flow is a hydraulic equivalent diameter for the flow along the tubes in the embodiment. The characteristic length D will be a tube inner diameter for a flow inside the tube. The air flow turbulence caused by one of the heat-transfer enhancing structures 107 is dampened toward the downstream due to viscosity of the fluid. As the turbulence is dampened, the thickness of the heat conduction layer increases, preventing the micro porous layer 110 from producing the heat-transfer enhancement effect. Thus, the plurality of heat-transfer enhancing structures 107 is installed in the direction of the flow to maintain the turbulence. Fig. 7 is a graph of a test result with parameters of a clearance L between the heat-transfer enhancing structures 107 in the flow direction and the height H of the heat-transfer enhancing structures 107. The clearance L in the flow direction refers to an installation clearance between the heat-transfer enhancing structures 107 on the heat transfer tube outer surface 106. In Fig. 3, the clearance L in the flow direction is the clearance between the vertexes of triangular sections of the heat-transfer enhancing structures 107. The height H of the heat-transfer enhancing structures 107 refers to a height from the bottom to the vertex of one of the triangular sections of the heat-transfer enhancing structures 107. The heat-transfer enhancement ratio is a ratio to a value with L/H ≈ 100. This test result demonstrates that a high heat-transfer enhancement ratio is obtained under a condition of L/H ≤ 300, and thus the heat-transfer enhancing structures 107 desirably satisfy the relationship of L/H ≤ 300.

[0018] A result of a component test will now be discussed, which has been conducted for a heat-transfer performance improvement ratio with the micro porous layer 110 and the heat-transfer enhancing structures 107 used in combination. The component test has been conducted with a low-velocity flow field at the flow velocity of 10 m/s. Fig. 8 is a graph of heat-transfer performance improvement ratios obtained during the component test. The heat-transfer performance improvement ratio is a ratio to a value with the turbulent flow enhancement ribs. It has been demonstrated that the combined use of the surface treatment and the turbulent flow enhancement ribs yields an improvement in heat-transfer performance over the sum simply calculated of the surface treatment and the turbulent flow enhancement ribs used alone, thus generating synergistic effect.

[0019] Under high flow velocity conditions, in which the micro porous layer 110 used alone can yield the heat-transfer enhancement effect, the arrangement according to the embodiment with the use of the heat-transfer enhancing structures further reduces the thickness of the heat conduction layer, thereby further increasing the heat-transfer enhancement effect of the micro porous layer.

[0020] The embodiment described above can produce the heat-transfer enhancement effect even under low air flow velocity conditions. In comparison with a heat exchanger with the micro porous layers alone applied to the heat transfer tube outer surfaces, the embodiment can further increase the heat-transfer enhancement effect under an identical flow velocity condition. In comparison with a heat exchanger without the embodiment, the embodiment can achieve an improvement in heat-transfer performance, thereby reducing the number of heat transfer tubes and reducing costs of the heat exchanger.

Second embodiment

[0021] A second embodiment is a shell and tube heat exchanger with the heat-transfer device applied. This embodiment is capable of improving the heat-transfer performance even under conditions of low flow velocities of a fluid used for heat exchange, in comparison with a conventional shell and tube heat exchanger. The embodiment can also curb vibration of heat transfer tubes that accompanies the condensation of vapor.

[0022] Fig. 4 is a structure diagram of the shell and tube heat exchanger according to the second embodiment. Fig. 5 is a sectional view taken along line A-A of Fig. 4. The shell and tube heat exchanger in Fig. 4 will now be described, with an omission of parts indicated with the same reference numerals and having similar functions with those in the arrangement described in Fig. 1.

[0023] A micro porous layer 110 described in the first embodiment is formed on the outer surface of each heat transfer tube 101 to enhance heat transfer. A plurality of heat-transfer enhancing structures 112 is installed to obtain the heat-transfer enhancement effect of the micro porous layer 110 under low air flow velocity conditions. The heat-transfer enhancing structures 112 according to the embodiment are formed with rods. The heat-transfer enhancing structures 112 are made with a metal material, such as aluminum, copper, and SUS. Other materials, such as a heat resistant rubber and a heat resistant resin, may be used to improve manufacturability. The heat-transfer enhancing structures 112 may each have a section of any form, such as triangular, rectangular, and circular sections, as long as its height H [m] can be defined. Each of the heat-transfer enhancing structures 112 is secured at both ends to an inner surface of a shell 100 through welding or bonding. The heat-transfer enhancing structures 112 are arranged so that the heat transfer tubes 101 are interposed therebetween, thereby securing the heat transfer tubes 101. This can curb the vibration of the heat transfer tubes 101 due to reasons including vapor condensation within the tubes. The heat-transfer enhancing structures 112 cause turbulence to obtain the heat-transfer enhancement effect of the micro porous layer 110 even under low air flow velocity conditions. To allow the heat-transfer enhancing structures 112 to generate sufficient turbulence, the height H of the heat-transfer enhancing structures 112 desirably satisfies its relationship to the characteristic length D [m] of the flow of $H/D \geq 0.01$. The characteristic length D of the flow is a hydraulic equivalent diameter for the flow along the tubes in the embodiment. The characteristic length D will be a tube inner diameter for a flow inside the tube. The air flow turbulence caused by one of the heat-transfer enhancing structures 112 is dampened toward the downstream due to viscosity of the fluid. To maintain the turbulence, the plurality of heat-transfer enhancing structures 112 is installed in the flow direction. A clearance L between the heat-transfer enhancing structures 112 in the flow direction desirably satisfies $L/H \leq 300$ in consideration of the dampening effect of the fluid viscosity on the turbulence. Under high flow velocity conditions, in which the micro porous layer 110 used alone can yield the heat-transfer enhancement effect, the arrangement according to the embodiment with the use of the heat-transfer enhancing structures further reduces the thickness of the heat conduction layer, thereby further increasing the heat-transfer enhancement effect of the micro porous layer.

[0024] The embodiment described above can produce the heat-transfer enhancement effect even under low air flow velocity conditions. In comparison with a heat exchanger with the micro porous layers alone applied to the heat transfer tube outer surfaces, the embodiment can further increase the heat-transfer enhancement effect under an identical flow velocity condition. In comparison with a heat exchanger without the embodiment, the embodiment can achieve an improvement in heat-transfer performance, thereby reducing the number of heat transfer tubes and reducing costs of the heat exchanger. Additionally, the embodiment can curb the vibration of the heat transfer tubes that accompanies the condensation of vapor.

[0025] Features, components and specific details of the structures of the above-described embodiments may be exchanged or combined to form further embodiments optimized for the respective application. As far as those modifications are apparent for an expert skilled in the art they shall be disclosed implicitly by the above description without specifying explicitly every possible combination.

Claims

1. A heat-transfer device including a heat transfer tube (101) arranged inside a shell (100), the heat transfer tube (101) being configured to allow a hot fluid (108) to flow inside thereof and a cold fluid to flow outside thereof for heat exchange through convective heat transfer, the device comprising a micro porous layer (110) and a plurality of heat-transfer enhancing structures (107, 112) on a surface (106) of the heat transfer tube (101), the surface being in contact with the cold fluid, wherein the heat-transfer enhancing structures (107, 112) have a height H that satisfies a relationship to a flow characteristic length D of $0.05 > H/D \geq 0.01$, and a relationship to an installation clearance L between the heat-transfer enhancing structures in a flow direction of $40 < L/H \leq 300$.
2. The heat-transfer device according to claim 1, wherein each of the heat-transfer enhancing structures (107, 112) is secured at both ends to an inner surface of the shell (100).
3. The heat-transfer device according to claim 1 or 2, wherein the micro porous layer (110) has asperities thereon with an average height not more than 10 μm .

FIG. 1

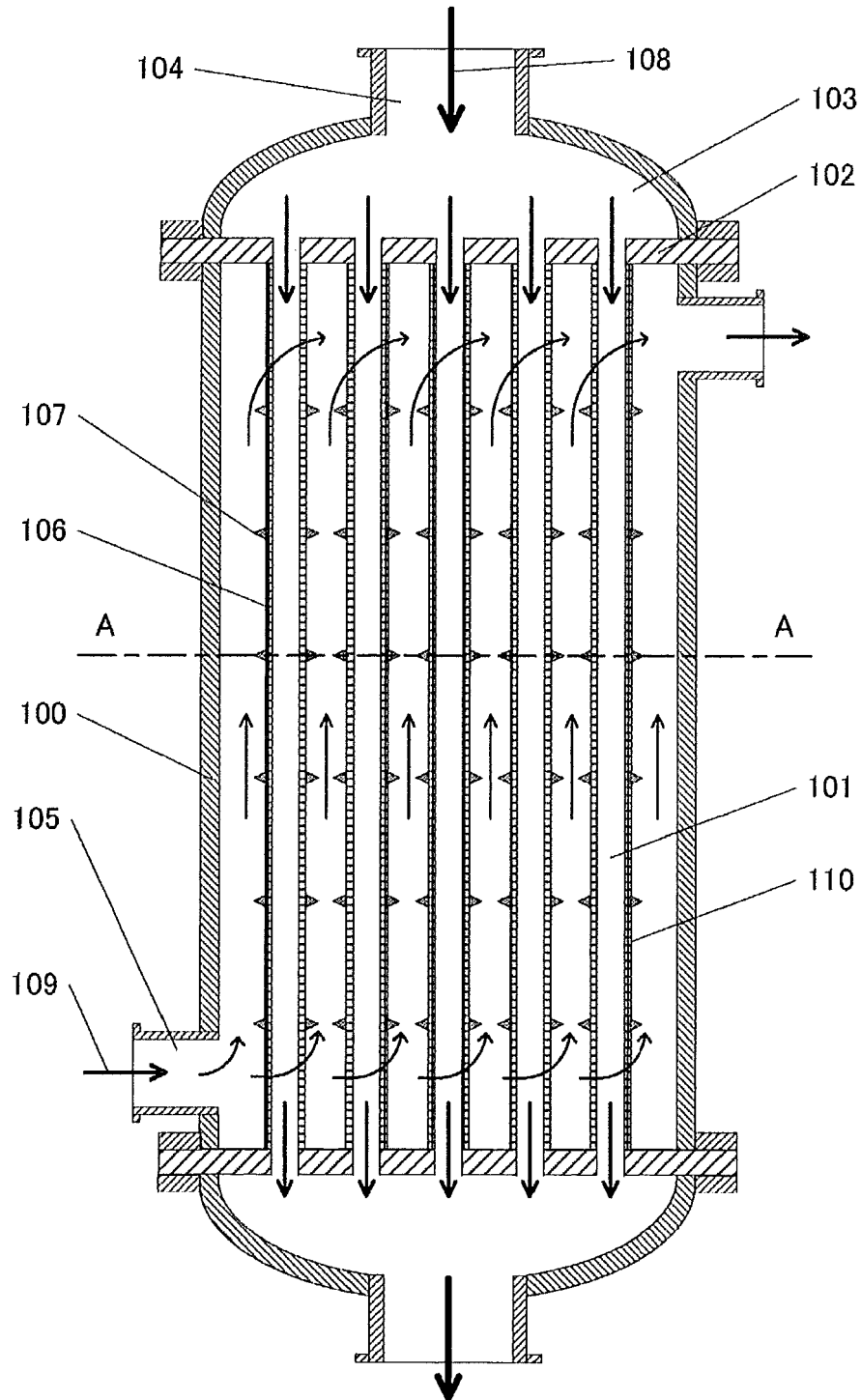


FIG. 2

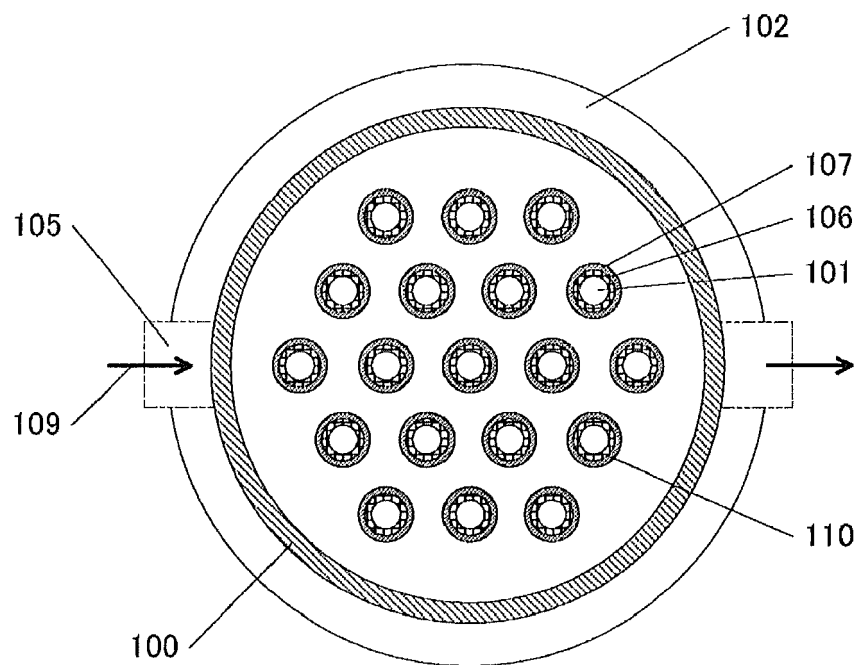


FIG. 3

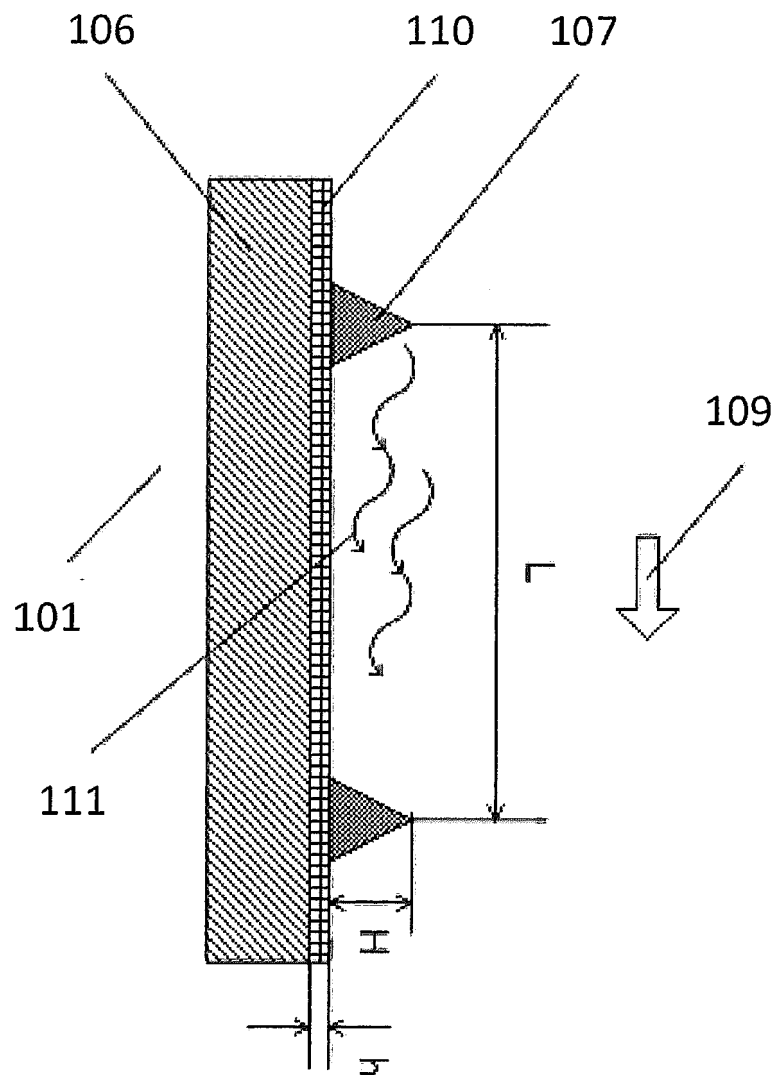


FIG. 4

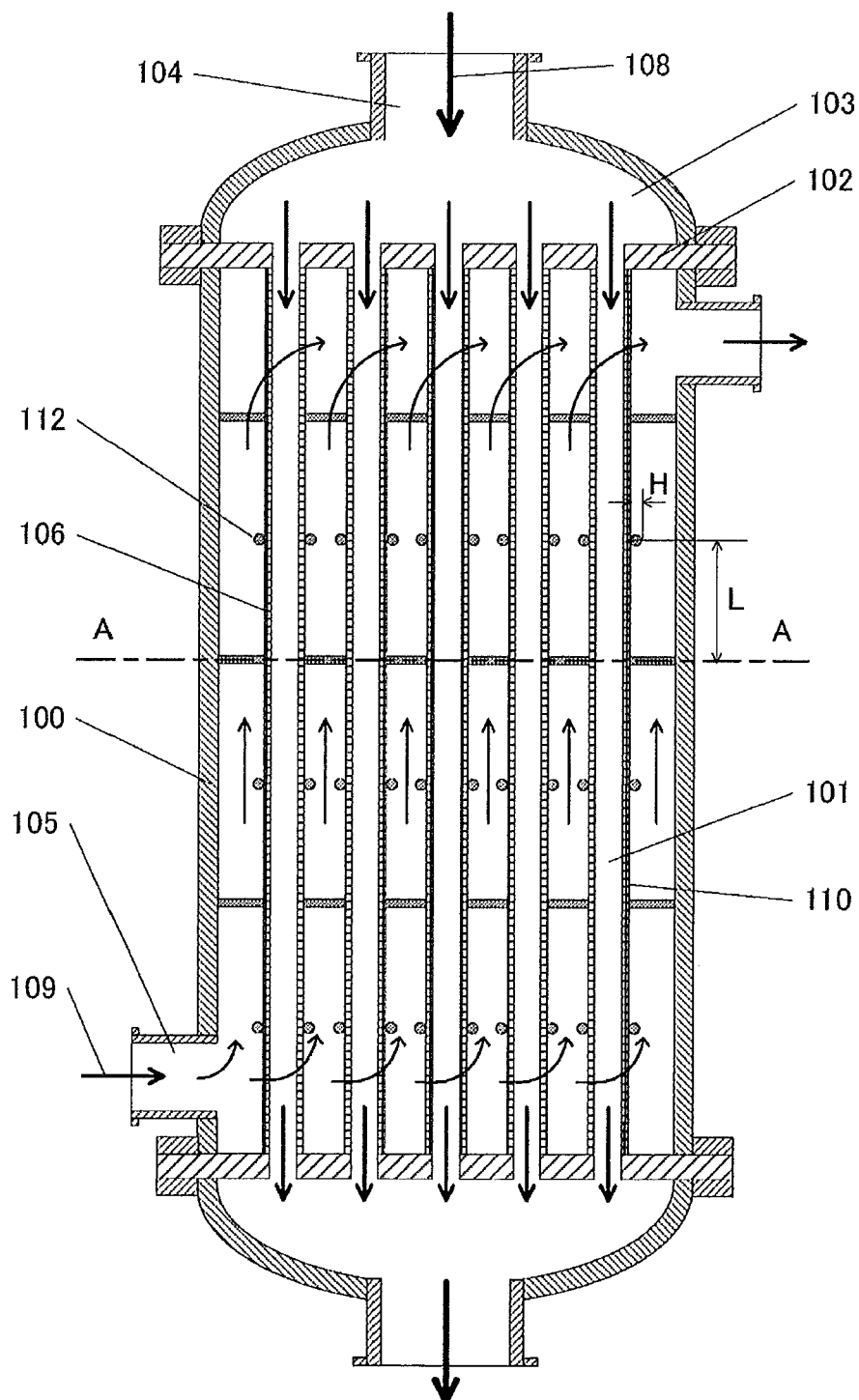


FIG. 5

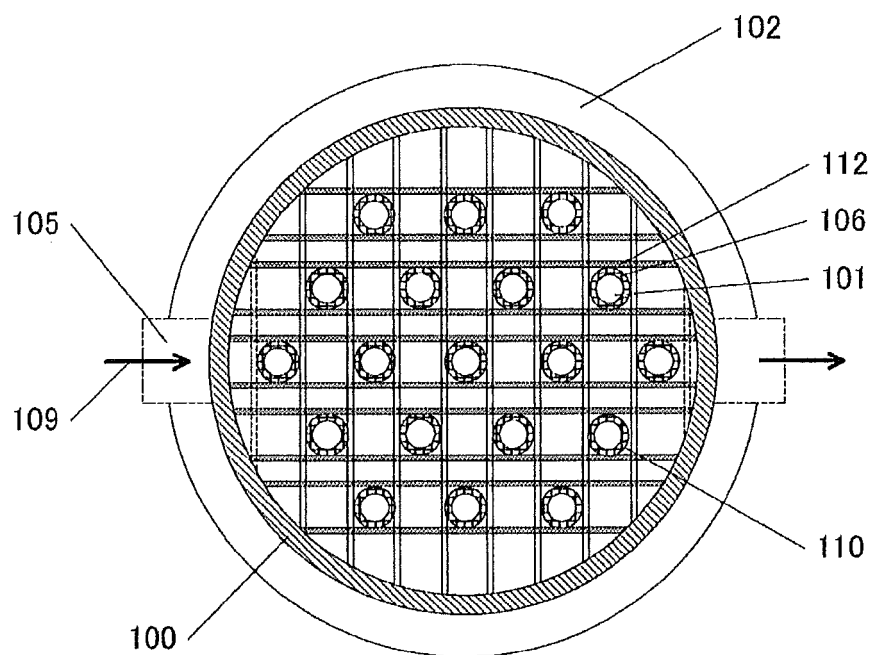


FIG. 6

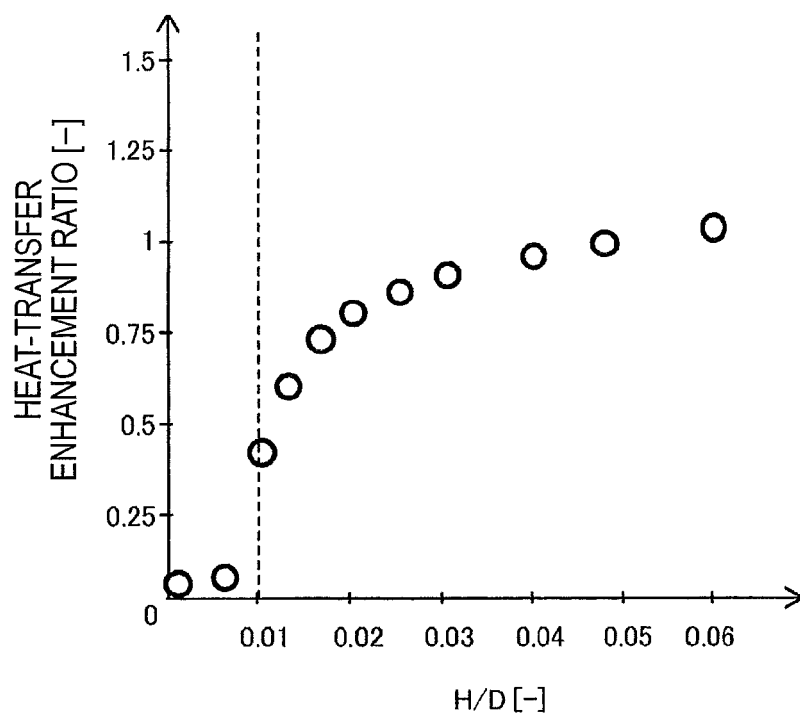


FIG. 7

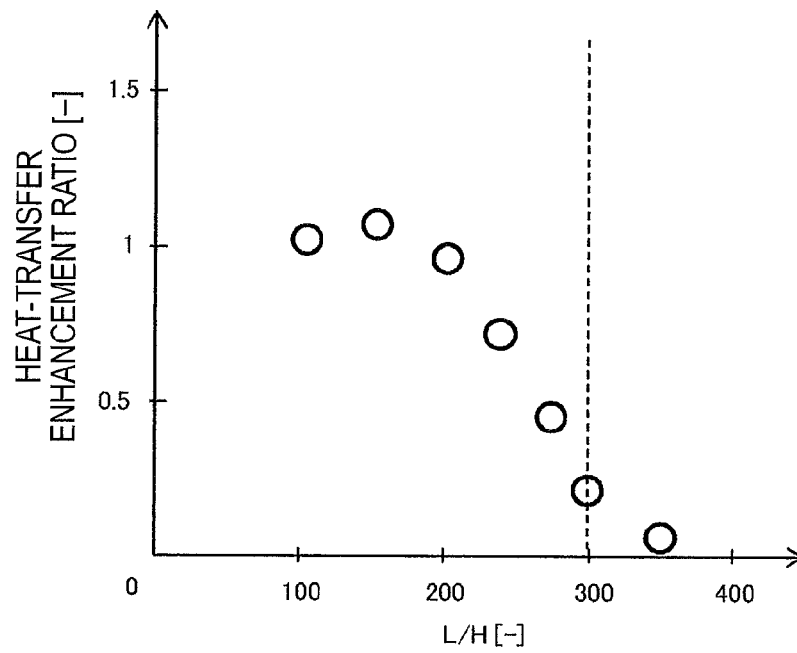
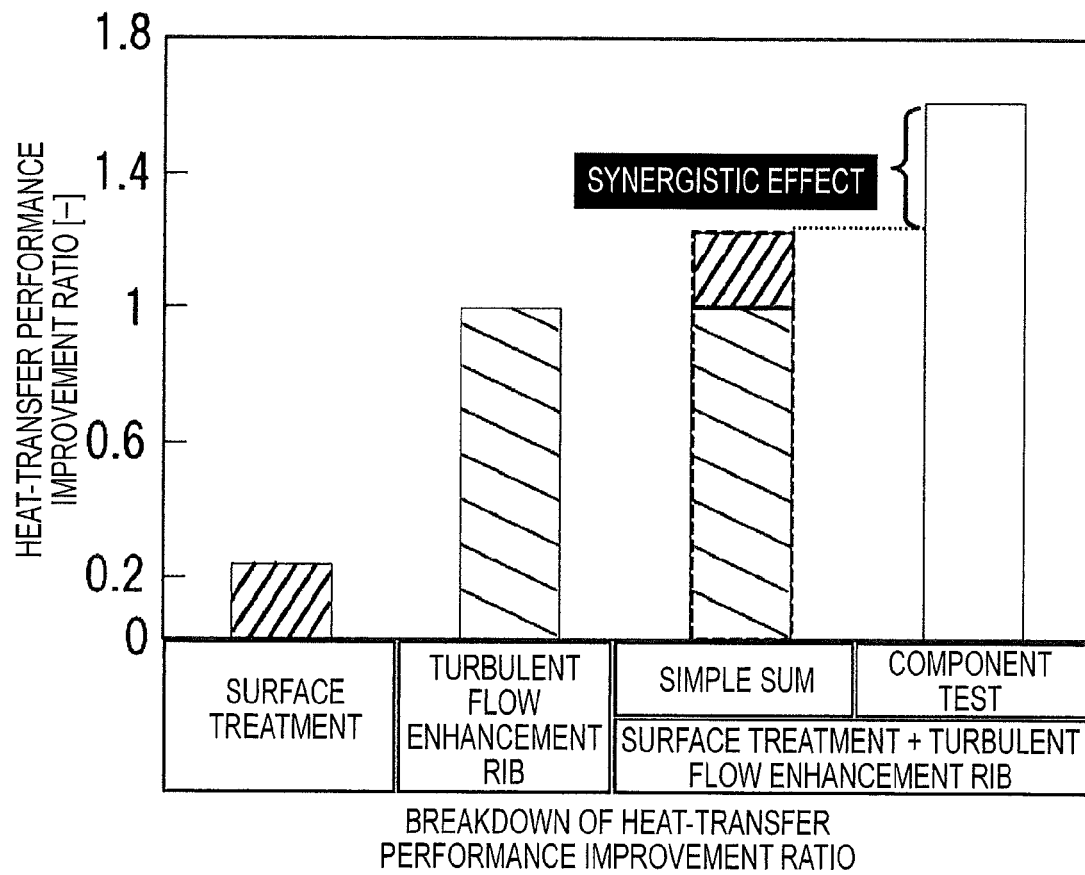


FIG. 8





EUROPEAN SEARCH REPORT

 Application Number
EP 14 17 4020

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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 5 December 2014	Examiner Louchet, Nicolas
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EPO FORM 1503.03.82 (P04C01)

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