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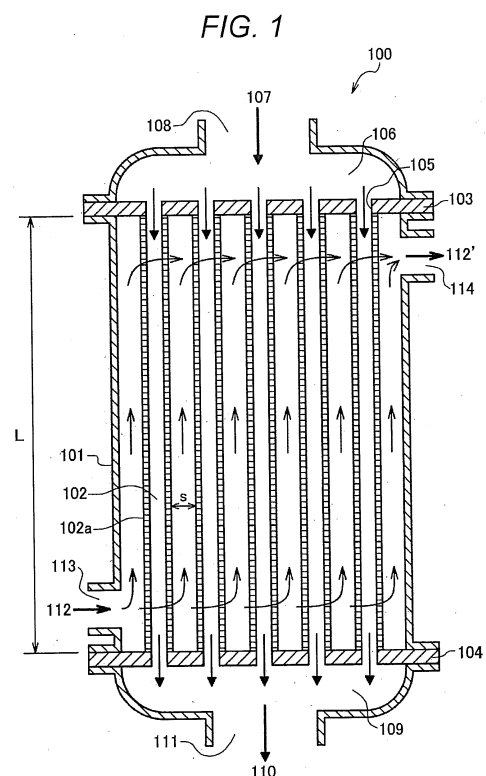
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(54) **HEAT EXCHANGER**

(57) Provided is a heat exchanger having improved heat transfer performance. A heat exchanger (100) according to the present invention includes a heat transfer unit (102) configured to perform heat exchange by contact with gas (112), and a contact surface (102a) of the heat transfer unit (102) to be in contact with the gas (112) is provided with a fine structure body (102b) which has a height of 10 μm or less and a surface area of 10 times or more of a smooth surface. The gas (112) desirably has a Reynolds number of 30,000 or more, and the fine structure body (102b) is desirably formed of the same material as that of a base material forming the contact surface (102a). Moreover, the fine structure body (102b) desirably has heat conductivity equal to or larger than the base material forming the contact surface (102a).



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**Description**

Technical Field

5 **[0001]** The present invention relates to a heat exchanger.

Background Art

10 **[0002]** New heat transfer enhancement techniques configured to improve the heat transfer performance of a heat exchanger are described in PTLs 1 and 2. A heat transfer enhancement technique described in PTL 1 is intended to improve convective heat transfer by forming a nanoparticle porous layer on a heat transfer surface and enhancing molecular diffusion at a heat conduction area in a boundary layer. Specifically, described in PTL 1 is a heat transfer medium including: a dense solid body; a porous lower layer which is formed on a surface of the solid body and is composed of first particles that are formed of copper oxide particulates having an average diameter of 1  $\mu\text{m}$  or less and have substantially spherical shapes; and a porous upper layer which is formed on the porous lower layer and is composed of second particles that are formed of copper oxide nanoparticles having an average diameter of 0.1  $\mu\text{m}$  or less and have various shapes.

15 **[0003]** Moreover, a heat transfer enhancement technique described in PTL 2 is intended to form a nanoporous layer on a heat transfer surface. Specifically, described in PTL 2 is a heat exchanger having a nanoporous layer formed on at least a part of a heat transfer surface thermally connected with a heat-exchange object such as air or a semiconductor element, wherein at least a part of the heat transfer surface on which the nanoporous layer is formed is provided within an entrance region of a laminar flow.

Citation List

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Patent Literatures

**[0004]**

30 PTL 1: Publication of Patent No. 3,629,029  
PTL 2: Unexamined Patent Application Publication No. 2006-132841

Summary of Invention

35 Technical Problem

**[0005]** Although it can be said that the technique described in PTL 1 is epoch-making in that the technique improves heat transfer performance without using the boundary layer theory, there is still room for improvement of heat, transfer performance.

40 **[0006]** Moreover, although a relation between the heat transfer performance and the boundary layer thickness is described in PTL 2, no study is made on the shape or size of a fine structure body forming a nanoporous layer, and there is still room for improvement of heat transfer performance.

**[0007]** An object of the present invention is to provide a heat exchanger capable of improving heat transfer performance.

45 Solution to Problem

**[0008]** To achieve the object described above, a heat exchanger of the present invention includes a heat transfer unit configured to perform heat exchange by contact with gas, and a contact surface of the heat transfer unit to be in contact with the gas is provided with a fin structure body which has a height of 10  $\mu\text{m}$  or less and a surface area of 10 times or more of a smooth surface.

Advantageous Effects of Invention

55 **[0009]** According to the present invention, it is possible to provide a heat exchanger capable of improving heat transfer performance.

## Brief Description of Drawings

**[0010]**

- 5 [FIG. 1] FIG. 1 is a sectional view illustrating one aspect of a heat exchanger according to this embodiment.  
 [FIG. 2] FIG. 2 is a schematic diagram which provides an enlarged view of a surface of a heat transfer unit 102 to be in contact with gas 112.  
 [FIG. 3] FIG. 3 is an SEM image obtained by imaging a surface of a fine structure body 102b according to one aspect, wherein the scale bar indicates 1  $\mu\text{m}$ .  
 10 [FIG. 4] FIG. 4 is an SEM image obtained by imaging a cross section of the same fine structure body 102b as that of FIG. 3, wherein the scale bar indicates 1  $\mu\text{m}$ .  
 [FIG. 5] FIG. 5 is an SEM image obtained by imaging a surface of a fine structure body 102b according to another aspect, wherein the scale bar indicates 1  $\mu\text{m}$ .  
 [FIG. 6] FIG. 6 is an SEM image obtained by imaging a cross section of the same fine structure body 102b as that  
 15 of FIG. 5, wherein the scale bar indicates 1  $\mu\text{m}$ .  
 [FIG. 7] FIG. 7 is a block diagram of a testing device used for conducting a heat transfer test.  
 [FIG. 8] FIG. 8 is a sectional view taken along line A-A of FIG. 7.

**[0011]** Description of Embodiments

20 **[0012]** An embodiment of a heat exchanger according to the present invention is hereinafter described in detail with reference to proper figures.

**[0013]** A heat exchanger according to this embodiment is a so-called air-cooled heat exchanger which performs heat exchange using gas. Examples of such a heat exchanger include a shell and tube type heat exchanger, a fin type heat exchanger (heat sink) for a power semiconductor, or a cross fin type heat exchanger for a radiator in an automobile or  
 25 an air conditioner, though the present invention is not limited thereto.

**[0014]** A heat transfer unit provided in a heat exchanger according to this embodiment takes various forms depending on the form of a heat exchanger. For example, a tube member (heat transfer tube) having a circular or rectangular cross section corresponds to a heat transfer unit in the case of a shell and tube type heat exchanger. When such a tube member is employed, it is to be noted that a fin may be or may be not provided on at least one of an outer surface and  
 30 an inner surface thereof spirally or parallel along the longitudinal direction, preferably without disturbing the gas flow. Moreover, a plurality of fins provided on a surface on the reverse side of a surface attached to a heat source, a base material surface between fins, or the like correspond to a heat transfer unit in the case of a heat sink. In addition, a fin which is penetrated a plurality of times by hollow linear tubes connected by hollow U-shaped tubes corresponds to a heat transfer unit in the case of a cross fin type heat exchanger. In addition, in the present invention, a fine structure  
 35 body having specific conditions is provided on a surface of a heat transfer unit to be in contact with gas, that is, a surface of a heat transfer tube, a surface of a fin, a base material surface between fins, and the like. It is to be noted that the fine structure body having specific conditions will be described later.

**[0015]** Gas may flow in forced convection or in free convection. Force convection means a gas flow generated forcibly by external force, while free convection means a gas flow in a case where a flow by external force is weak or external  
 40 force does not exist. In the case of forced convection, it is generally said that a larger Reynolds number (Re) (e.g., Re of 4,000 or larger) tends to cause a turbulent flow, while a smaller Reynolds number (e.g., Re of 2,300 or smaller) tends to cause a laminar flow. In addition, in the case of free convection, it is said that a laminar flow tends to be caused. It is to be noted that a turbulent flow means a spatially and temporally irregular flow, while a laminar flow means a flow wherein the stream line of gas in a tube is always parallel to the tube axis, for example.

45 **[0016]** FIG. 1 is a sectional view illustrating one aspect of a heat exchanger 100 according to this embodiment. It is to be noted that the heat exchanger 100 is a shell and tube type heat exchanger.

**[0017]** Such a heat exchanger 100 is provided with tube plates 103 and 104 configured to support heat transfer units 102, respectively on an upper side and a lower side of a circular or polygonal shell 101.

50 **[0018]** At the tube plates 103 and 104, a number of tube holes 105 through which the heat transfer units 102 pass are arranged zigzag. Each heat transfer unit 102 is inserted into each tube hole 105 and fixed to the tube plates 103 and 104 at both ends thereof. It is to be noted that such a heat transfer unit 102 is provided in a shell and tube type heat exchanger, and thus is a heat transfer tube having a circular or rectangular cross section as described above.

**[0019]** Moreover, a water chamber 106 is provided above the upper tube plate 103. The water chamber 106 is provided with a nozzle 108 configured to introduce water vapor 107, which is an object of heat exchange and is high-temperature  
 55 fluid.

**[0020]** On the other hand, a water chamber 109 is provided below the lower tube plate 104. The water chamber 109 is provided with a nozzle 111 configured to discharge condensed water 110, which is generated by condensation of water vapor 107 exposed to heat transfer, from the device.

**[0021]** In addition, a nozzle 113 configured to introduce gas (air) 112, which is low-temperature fluid, into the device is provided on a lower side surface of the shell 101.

**[0022]** On the other hand, a nozzle 114 configured to discharge gas 112', which has been introduced into the device, from the device is provided on an upper side surface of the shell 101.

**[0023]** It is to be noted that each heat transfer unit 102 described above is desirably formed of copper or copper alloy having excellent heat conductivity. The respective components of the heat exchanger 100 other than the heat transfer units 102 may be formed using stainless steel, copper, aluminum, nickel, titanium, or alloy thereof.

**[0024]** In the heat exchanger 100 having such a structure, while water vapor 107 introduced from above the shell 101 into the device flows downward in the heat transfer units 102, gas 112 which is introduced from below into the device and goes upward between a plurality of heat transfer units 102 performs heat transfer via a tube wall of each heat transfer unit 102. As a result, water vapor 107 which has been at a high temperature is cooled by gas 112 and condensed into condensed water 110, and is discharged from the device through the nozzle 111. On the other hand, gas 112' the temperature of which has been raised as a result of heat transfer is discharged from the device through the nozzle 114.

**[0025]** In addition, in the heat exchanger 100 according to the present invention, each heat transfer unit 102 is provided with a contact surface 102a to be in contact with gas 112 in order to improve the heat transfer performance.

**[0026]** It is to be noted that FIG. 2 is a schematic diagram which provides an enlarged view of a surface of a heat transfer unit 102 at a side to be in contact with gas 112 in order to describe a fine structure body 102b. Moreover, FIGS. 3 to 6 are Scanning Electron Microscopy (SEM) images illustrating concrete examples of a fine structure body 102b; FIG. 3 is an SEM image obtained by imaging a surface of a fine structure body 102b according to one aspect, while FIG. 4 is an SEM image obtained by imaging a cross section of the same fine structure body 102b. Moreover, FIG. 5 is an SEM image obtained by imaging a surface of a fine structure body 102b according to another aspect, while FIG. 6 is an SEM image obtained by imaging a cross section of the same fine structure body 102b. It is to be noted that a scale bar in each of FIGS. 3 to 6 indicates 1  $\mu\text{m}$ .

**[0027]** Each of the fine structural bodies 102b illustrated in FIGS. 2 to 6 has a height  $h$  (see FIG. 2) of 10  $\mu\text{m}$  or less and a surface area of ten times or more of a smooth surface.

**[0028]** The heat transfer performance can be improved when a condition that the height  $h$  of a fine structure body 102b is 10  $\mu\text{m}$  or less and a condition that the surface area is ten times or more of a case of a smooth surface are simultaneously satisfied.

**[0029]** The heat transfer performance cannot be improved when the height  $h$  of a fine structure body 102b exceeds 10  $\mu\text{m}$  or when the surface area is smaller than ten times of a smooth surface. It is to be noted that, although the height  $h$  of a fine structure body 102b exceeding a boundary layer can provide a high cooling effect, pressure loss occurs as a trade-off therefor. When pressure loss occurs, the heat transfer performance is sometimes not improved totally. Moreover, when the surface area is smaller than ten times of a smooth surface, high heat transfer performance cannot be obtained. It is to be noted that a boundary layer means a thin layer which exists in the vicinity of a boundary of a contact surface 102a and in which gas viscosity cannot be neglected (which is strongly influenced by gas viscosity).

**[0030]** In addition, although the heat transfer performance of the heat exchanger 100 can be improved even when the gas flow is a laminar flow, the gas flow is desirably a turbulent flow since the heat transfer performance of the heat exchanger 100 can be further improved. It is further desirable that the Reynolds number of gas is 30,000 or larger. In such a case, it is possible to improve the heat transfer performance of the heat exchanger 100 more reliably. The Reynolds number of gas can be 30,000 by increasing the flow rate of gas introduced through the nozzle 113 into the device.

**[0031]** The fine structure body 102b is desirably made of the same material as the base material of the heat transfer units 102, i.e., copper or copper alloy, and is more desirably not made of an oxide thereof. When the fine structure body 102b is made of an oxide of copper or copper alloy, the heat conductivity lowers and the heat transfer performance of the heat exchanger 100 lowers. In other words, when the fine structure body 102b is made of the same material as the base material of the heat transfer unit 102, heat conductivity equal to or larger than the base material can be provided. That is, heat transferred through the heat transfer units 102 can be efficiently transferred to gas.

**[0032]** The shape of the fine structure body 102b is desirably a dendritic structure or a needle-like structure. Here, a dendritic structure means a structure having branches from the center toward the outside, while a needle-like structure literally means a structure like a needle. Such structures can enlarge the surface area and improve the heat transfer performance of the heat exchanger 100 more reliably.

**[0033]** Explanation is continued returning to FIG. 1. As illustrated in FIG. 1, the length  $L$  of the heat transfer unit 102 provided with the fine structure body 102b (see FIG. 2) is 25 times or more of the characteristic length of the flow. It is to be noted that a characteristic length of a flow in this embodiment corresponds to the hydraulic equivalent diameter of a flow along tube holes 104 (tubes). A hydraulic equivalent diameter means the diameter of a circular tube equivalent to a cross section of a flow passage and can be represented as  $4S_1/L_1$ . It is to be noted that  $S_1$  denotes a flow passage cross sectional area, and  $L_1$  denotes a cross sectional length. Thus, when the length  $L$  of the heat transfer unit 102 is 25 times or more of the characteristic length of the flow, the heat transfer performance can be further improved in a case where the gas flow state is a turbulent flow.

**[0034]** On the other hand, there is no special limitation on a contact surface, which is a rear surface of the contact surface 102a, to be in contact with water vapor 107, and a fine structure body similar to the above-described fine structure body 102b may be or may be not provided. Moreover, a fine structure body having a shape, size, surface area, height or the like different from that of the fine structure body 102b can be provided on the contact surface to be in contact with

water vapor 107.

**[0035]** One suitable method to form the above-described fine structure body 102b on a surface of the heat transfer unit 102 is Multibond treatment or blackening reduction treatment, and the fine structure body 102b is desirably formed by such treatment.

**[0036]** Multibond treatment can be achieved by using cleaning liquid, pre-dip liquid and Multibond liquid manufactured by Nippon Macbermid Co., Ltd., for example, and performing treatment in this order.

**[0037]** Conditions for treatment with cleaning liquid can be a liquid temperature of 50°C and a treatment time of 3 minutes, for example. Conditions for treatment with pre-dip liquid can be a liquid temperature of 25°C and a treatment time of 1 minute, for example. Conditions for treatment with Multibond liquid can be a liquid temperature of 32°C, a treatment time of 2 minutes, and the like, for example. It is to be noted that these conditions can be modified as appropriate, and washing with water or drying can be performed as appropriate after each treatment.

**[0038]** Moreover, regarding blackening reduction treatment, etching with copper etching liquid including ammonium persulfate may be performed after degreasing with degreasing liquid including NaOH, for example; an oxide film may be then removed by oxide film removing liquid including sulfuric acid; blackening treatment with blackening treatment liquid including sodium chlorite, sodium hydroxide and sodium phosphate may be then performed; and reduction treatment with reduction treatment liquid including dimethylamine borane may be then performed.

**[0039]** Conditions for treatment with degreasing liquid can be a liquid temperature of 60°C and a treatment time of 3 minutes, for example, and conditions for treatment with copper etching liquid can be a liquid temperature of 25°C and a treatment time of 1 minute, for example. Moreover, conditions for treatment with oxide film removing liquid can be a liquid temperature of 25°C and a treatment time of 3 minutes, for example, and conditions for treatment with blackening treatment liquid can be a liquid temperature of 70°C and a treatment time of 8 minutes, for example. In addition, conditions for treatment with reduction treatment liquid can be a liquid temperature of 25°C and a treatment time of 5 minutes, for example. It is to be noted that these conditions can be modified as appropriate, and washing with water or drying can be performed as appropriate after each treatment.

**[0040]** When performing the above-described Multibond treatment, the fine structure body 102b illustrated in FIGS. 3 and 4 can be obtained. When performing blackening reduction treatment, the fine structure body 102b illustrated in FIGS. 5 and 6 can be obtained.

**[0041]** With the heat exchanger 100 according to this embodiment described above, the contact surface 102a of the heat transfer unit 102 to be in contact with gas 112 is provided with the above-described fine structure body 102b, and therefore high heat transfer performance can be exhibited even when the gas flow is a laminar flow. In addition, further higher heat transfer performance can be exhibited when the gas flow is a turbulent flow.

**[0042]** The heat exchanger 100 according to this embodiment therefore can improve heat transfer performance without increasing the number of heat transfer units. Accordingly, it is possible to decrease the number of heat transfer units required to obtain target heat transfer performance, and therefore costs for a heat exchanger can be reduced. In addition, it is also possible to realize miniaturization and weight reduction of a heat exchanger.

#### Examples

**[0043]** Next, a heat exchanger according to the present invention is explained specifically using examples.

#### [1] Treatment No. 1; Treatment by Multibond Treatment

**[0044]** In Treatment No. 1, a dendritic structure body smaller than the boundary layer thickness was formed on a surface of a specimen prepared from a copper plate (C1020 prescribed in JIS H 3100) having the same chemical composition as that of a copper tube to be used as a heat transfer tube of a shell and tube type heat exchanger.

**[0045]** Such a dendritic structure body was formed using Multibond from Nippon MacDermid Co., Ltd., and was specifically formed as follows.

**[0046]** First, a copper plate was treated at a liquid temperature of 50°C for a treatment time of 3 minutes with cleaning liquid (MB-115; concentration of 100 mL/L), and was then washed with water.

**[0047]** Next, the copper plate was treated at a liquid temperature of 25°C for a treatment time of 1 minute with pre-dip liquid (MB-100B; concentration of 20 mL/L, MB-100C; concentration of 29 mL/L).

**[0048]** Finally, the copper plate was treated at a liquid temperature of 32°C for a treatment time of 2 minutes with Multibond liquid (MB-100A; concentration of 100 mL/L, MB-100B; concentration of 80 mL/L, MB-100-C; concentration of 43 mL/L, sulfuric acid concentration of 50 mL/L), and was then washed with water and dried.

**[0049]** The SEM image in FIG. 3 was obtained by imaging a surface of the copper plate with an SEM after performing the Multibond treatment, and the SEM image in FIG. 4 was obtained by imaging a cross section of the copper plate.

**[0050]** It was confirmed from the SEM image in FIG. 3 that a fine structure body of approximately 1 - 5  $\mu\text{m}$  (fine structure body) was formed irregularly. Moreover, it was confirmed from the SEM image in FIG. 4 that one fine structure body had a dendritic structure branched at several points and was continuously formed on the base material of the copper plate. It is to be noted that the dendritic structure body is the same copper as with the base material.

#### [2] Treatment No. 2; Treatment by Blackening Reduction Treatment

**[0051]** In Treatment No. 2, a needle-like structure body smaller than the boundary layer thickness was formed on a surface of a specimen prepared from the same copper plate as that of Treatment No. 1.

**[0052]** Such a needle-like structure body was formed by exposing the copper plate to blackening reduction treatment, and was specifically formed as follows.

**[0053]** First, the copper plate was treated at a liquid temperature of 60°C for a treatment time of 3 minutes with degreasing liquid (NaOH concentration of 40 g/L), and was then washed with water.

**[0054]** Next, the copper plate was treated at a liquid temperature of 25°C for a treatment time of 1 minute with copper etching liquid (Ammonium persulfate concentration of 200 g/L, sulfuric acid concentration of 5 mL/L), and was then washed with water.

**[0055]** Next, the copper plate was treated at a liquid temperature of 25°C for a treatment time of 3 minutes with oxide film removing liquid (sulfuric acid concentration of 30 mL/L), and was then washed with water.

**[0056]** Next, the copper plate was treated at a liquid temperature of 70°C for a treatment time of 8 minutes with blackening treatment liquid (sodium chlorite concentration of 90 g/L, sodium hydroxide concentration of 30 g/L, sodium phosphate concentration of 15 g/L), and was then washed with water.

**[0057]** Finally, the copper plate was treated at a liquid temperature of 25°C for a treatment time of 5 minutes with reduction treatment liquid (dimethylamine borane concentration of 30 g/L), and was then washed with water and dried.

**[0058]** The SEM image in FIG. 5 was obtained by imaging a surface of the copper plate with an SEM after performing the blackening reduction treatment, and the SEM image in FIG. 6 was obtained by imaging a cross section of the copper plate.

**[0059]** It was confirmed from the SEM image in FIG. 5 that a needle-like fine structure body (needle-like structure body) was densely formed. Moreover, it was confirmed from the SEM image in FIG. 6 that a needle-like structure body having a width of 0.1  $\mu\text{m}$  or less was continuously formed on the base material of the copper plate. It is to be noted that the needle-like structure body is copper as with the base material.

#### [3] Treatment No. 3; Treatment not by Reduction Treatment but only by Blackening Treatment

**[0060]** In Treatment No. 3, a needle-like structure body smaller than the boundary layer thickness was formed on a surface of a specimen prepared from the same copper plate as that of Treatment No. 1 in a way similar to Treatment No. 2. Here, the treatment with reduction treatment liquid described in Treatment No. 2 was not performed. That is, the copper plate was exposed to blackening treatment with blackening treatment liquid, and was then washed with water and dried, and all treatment was completed.

**[0061]** Similar to Treatment No. 2, a surface of the copper plate was imaged with an SEM after performing such blackening treatment, and it was confirmed that a fine needle-like structure body similar to that of Treatment No. 2 was densely formed. It was also confirmed that, on a surface of such a copper plate, a needle-like structure having a width of 0.1  $\mu\text{m}$  or less was continuously formed on the base material as the copper plate as with the copper plate of Treatment No. 2. It is to be noted that the needle-like structure body is copper oxide.

#### [4] Heat Transfer Test

##### [4-1] Structure of Testing Device Used for Heat Transfer Test

**[0062]** A heat transfer test was conducted using the copper plates treated by Treatment Nos. 1-3. FIG. 7 is a block diagram of a testing device 200 used for conducting a heat transfer test. Moreover, FIG. 8 is a sectional view taken along line A-A of FIG. 7.

**[0063]** As illustrated in FIG. 7, such a testing device 200 is provided with a rectangular tube 201, an air compressor 202, a panel heater 203 (see FIG. 8), an inlet thermometer 204, a specimen thermometer 205 and a mass flowmeter 206. The rectangular tube 201 is made of stainless steel, and has an entrance region 207 at an upstream part thereof and a heating region 208 at a central part thereof.

**[0064]** The entrance region 207 is provided, since heat transfer improvement effect appears even when the gas flow

state is a laminar flow but appears more strongly in a sufficiently developed turbulent flow boundary layer region. It is to be noted that a distance LL of the entrance region 207 can be expressed as Expression 1 wherein D denotes the characteristic length of the flow (see author/editor: Japan Society of Mechanical Engineers, JSME Textbook Series "Hydromechanics", publisher: Japan Society of Mechanical Engineers, issued in May, 2011, p. 90).

$$LL = (25 \text{ to } 40)D \quad \dots \text{ (Expression 1)}$$

**[0065]** In addition, a specimen 209 treated in Treatment No. 1 - 3 was located at an upper part of a heating region 208 of the rectangular tube 201 as illustrated in FIG. 8, and the panel heater 203 was located on an upper surface of the specimen 209. It is to be noted that the specimen 209 was located with a surface treated in Treatment No.1-3 (contact surface 102a in the present invention) existing inside the rectangular tube 201. Here, a surface on which the panel heater 203 is located is a smooth surface.

**[0066]** In addition, one thermocouple for temperature measurement is located in the entrance region 207 of the rectangular tube 201 as the inlet thermometer 204, and the other thermocouple is located inside the specimen 209 as the specimen thermometer 205.

**[0067]** Regarding such a testing device 200, it is to be noted that the outside of the rectangular tube 201 was thermally insulated with glass wool material in order to hinder heat conduction to the outside.

#### [4-2] Test Conditions of Heat Transfer Test

**[0068]** In a heat transfer test, an inlet air temperature and a wall temperature of the specimen 209 were measured in a state where the output of the panel heater 203 was set at 160 W, the heat flux was fixed, and the gas flow rate of the air compressor 202 was varied.

**[0069]** It is to be noted that the flow velocity of gas is 8 - 55 m/s, and the Reynolds number is 30, 000 - 180,000. The boundary layer thickness under these conditions is estimated to be 60 - 300  $\mu\text{m}$ .

#### [4-3] Rate of Improvement of Heat Conduction

**[0070]** The heat transfer coefficient calculated from a temperature measured in the heat transfer test was evaluated as the rate of improvement of heat conduction on the basis of a specimen having a smooth surface which has not been exposed to surface treatment.

#### [4-4] Surface Area Ratio

**[0071]** The surface area was measured by a krypton gas adsorption method. It is to be noted that the krypton gas adsorption method was performed according to JIS Z 8830. The measured surface area was evaluated as a surface area ratio based on a specimen having a smooth surface which has not been exposed to surface treatment.

**[0072]** The result of evaluation on the rate of improvement of heat conduction and the surface area ratio is shown in Table 1. It is to be noted that Table 1 additionally shows the height of a fine structure body calculated from an SEM image and the material of a fine structure body and the base material of a copper plate (described as "fine structure body/base material" in Table 1).

[Table 1]

	Rate of Improvement of Heat Conduction	Surface Area Ratio	Height of Fine Structure Body	Fine Structure Body/Base Material
Treatment No. 1	11%	58 times	2.3 $\mu\text{m}$	Copper/Copper
Treatment No. 2	10%	48 times	0.7 $\mu\text{m}$	Copper/Copper
Treatment No. 3	0%	48 times	0.7 $\mu\text{m}$	Copper Oxide/Copper

**[0073]** As shown in Table 1, the rate of improvement of heat conduction was 11% in Treatment No. 1, 10% in Treatment No. 2, and 0% in Treatment No. 3. The surface area ratio was 58 times in Treatment No. 1, and 48 times in Treatment

Nos. 2 and 3. Moreover, the height of a fine structure body was 2.3  $\mu\text{m}$  in Treatment No. 1, and 0.7  $\mu\text{m}$  in Treatment Nos. 2 and 3. In addition, the fine structure body/base material was copper/copper in Treatment Nos. 1 and 2, and copper oxide/copper in Treatment No. 3.

**[0074]** Since even a dendritic or needle-like structure body smaller than the boundary layer thickness exhibited a high rate of improvement of heat conduction as shown in Table 1, it was considered that the heat transfer enhancement effect in PTLs 1 and 2 were not peculiar to a nanoparticle porous layer.

**[0075]** Moreover, since the rate of improvement of heat conduction is high in Treatment No. 1 having the largest surface area ratio regardless of the shape of a fine structure body, it was shown that there was a correlation between the heat transfer performance and the surface area ratio.

**[0076]** Furthermore, since the rate of improvement of heat conduction is not enhanced in Treatment No. 3 wherein a fine structure body is formed of copper oxide and therefore the heat conductivity is lower than the base material, it was shown that the heat transfer performance is influenced by the heat conductivity of a fine structure body.

**[0077]** It was considered from these results that the main factor of heat transfer improvement effect by a fine structure body is what is correlated with the surface area ratio, i.e., enlargement of the heat transfer area. That is, it was considered that a fine structure body acts as a heat transfer area at a heat transfer member.

**[0078]** It is considered from the above discussion that a fine structure, which has heat conductivity equal to or larger than the base material and is smaller than the fluid boundary layer and can enlarge the surface area, is effective in order to improve the heat transfer performance.

**[0079]** Accordingly, it was confirmed that it was preferable that the height is 10  $\mu\text{m}$  or less and the surface area is 10 times or more of a smooth surface, and it was preferable that a fine structure body was made of the same material as that of the base material or, when the material of a fine structure body was different from that of the base material, heat conductivity was equal to or larger than that of the base material, in order to improve the heat transfer performance of a heat exchanger configured to perform heat exchange between gas and a heat transfer unit in a gas flow state where the Reynolds number of gas is 30,000 or larger.

**[0080]** Although a heat exchanger according to the present invention has been described above in detail using forms and examples designed to implement the present invention, the purport of the present invention is not limited to the contents described above but is to be interpreted widely on the basis of description of the claims. Moreover, various modification examples and variation examples are also included within the scope of the present invention.

**[0081]** For example, a method of forming a fine structure body having a height of 10  $\mu\text{m}$  or less and a surface area of 10 times or more of a smooth surface is not limited to the method described above but may be achieved by machining or the like.

#### Reference Signs List

**[0082]**

100 heat exchanger  
 102 heat transfer unit  
 102a contact surface  
 102b fine structure body  
 112 gas

#### Claims

1. A heat exchanger comprising a heat transfer unit configured to perform heat exchange by contact with gas, wherein a contact surface of the heat transfer unit to be in contact with the gas is provided with a fin structure body which has a height of 10  $\mu\text{m}$  or less and a surface area of 10 times or more of a smooth surface.
2. The heat exchanger according to claim 1, wherein the gas has a Reynolds number of 30,000 or more.
3. The heat exchanger according to claim 1, wherein the fine structure body is formed of the same material as that of the base material.
4. The heat exchanger according to claim 1, wherein the fine structure body has heat conductivity equal to or larger than the base material.
5. The heat exchanger according to claim 1, wherein the fine structure body has a shape of a dendritic structure or a

needle-like structure.

6. The heat exchanger according to claim 1, wherein the heat transfer unit has a length of 25 times or more of a characteristic length of a flow.

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7. The heat exchanger according to claim 1, wherein the base material is copper or copper alloy.

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FIG. 1

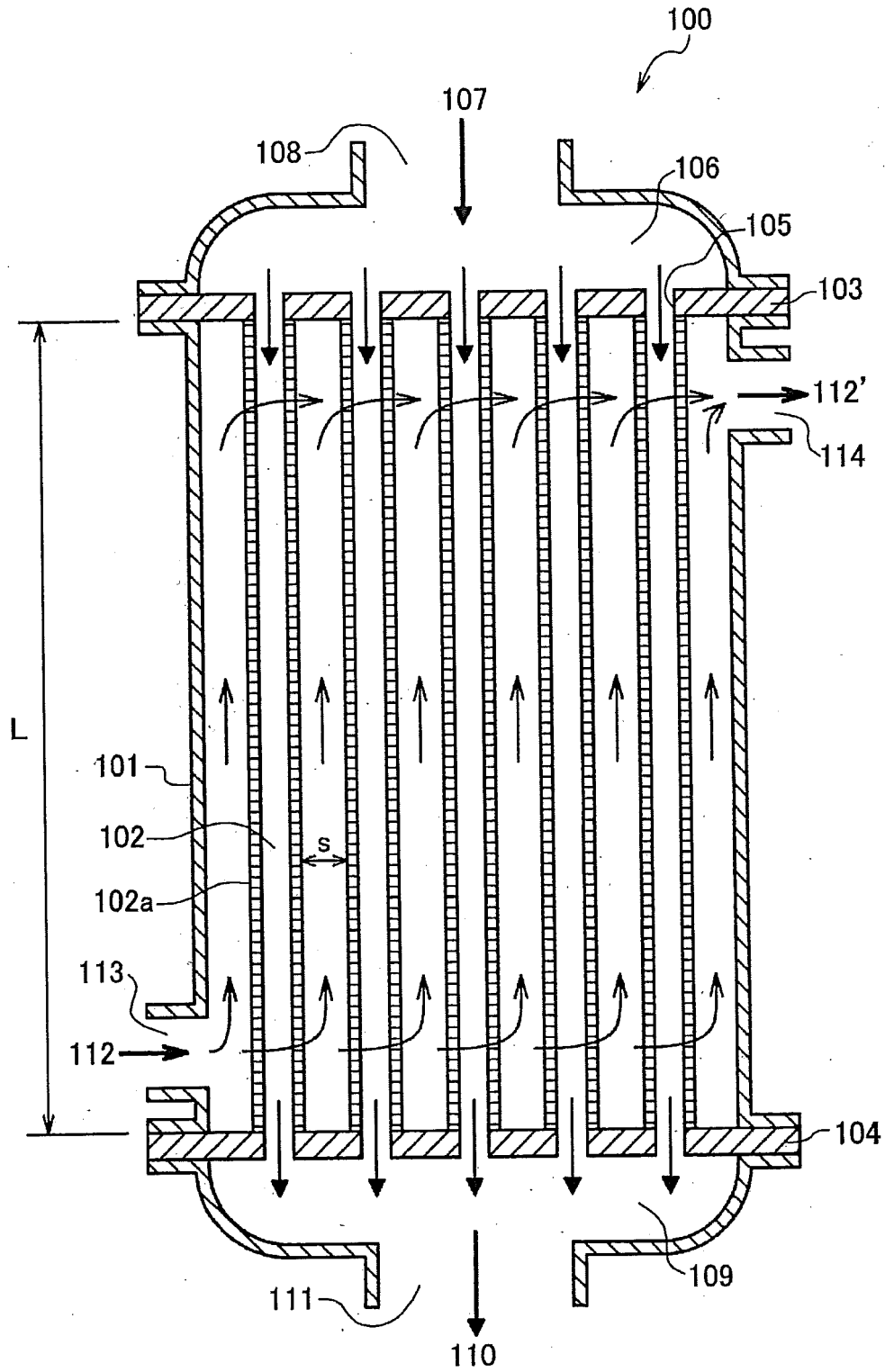
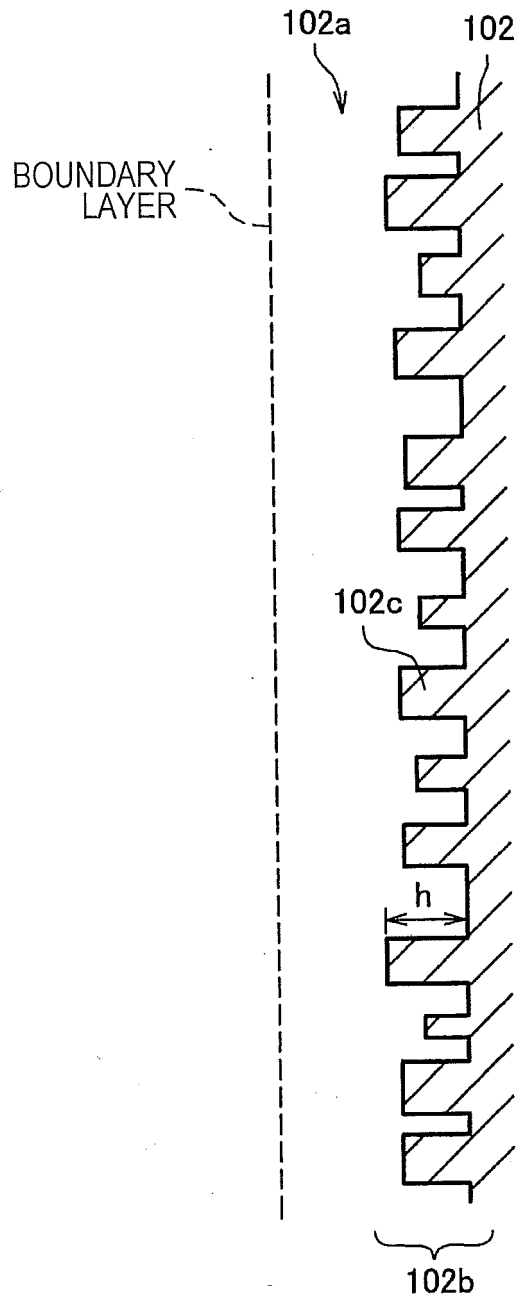
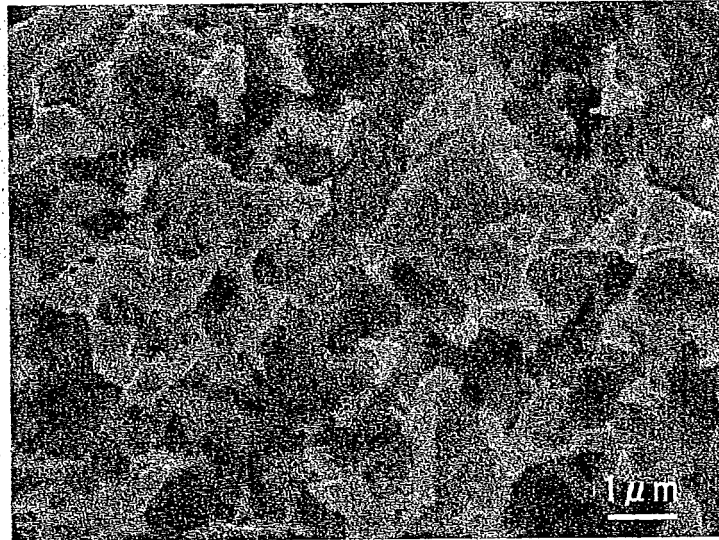


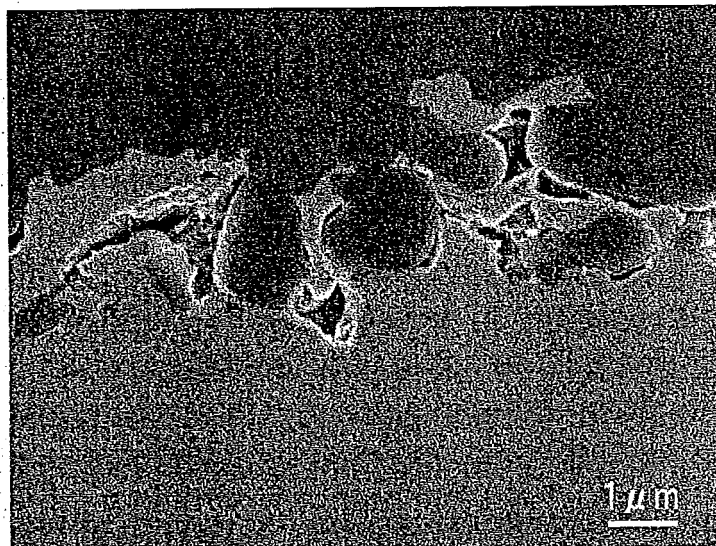
FIG. 2



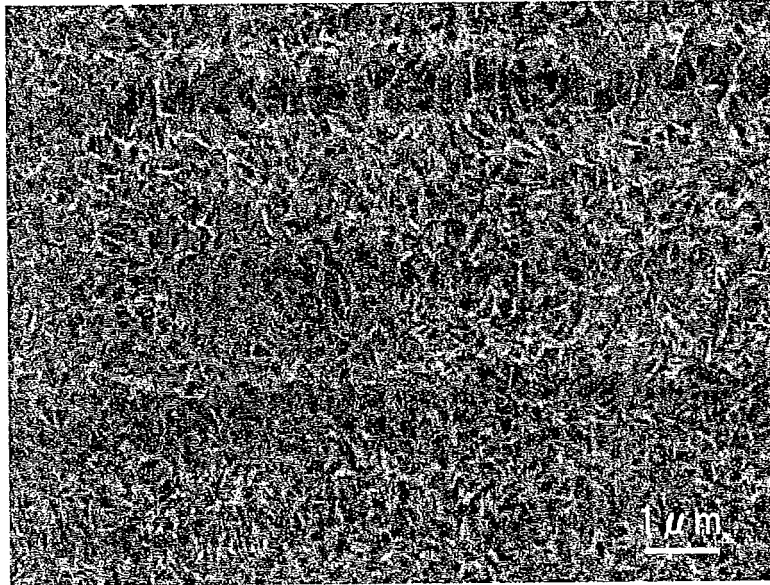
*FIG. 3*



*FIG. 4*



*FIG. 5*



*FIG. 6*

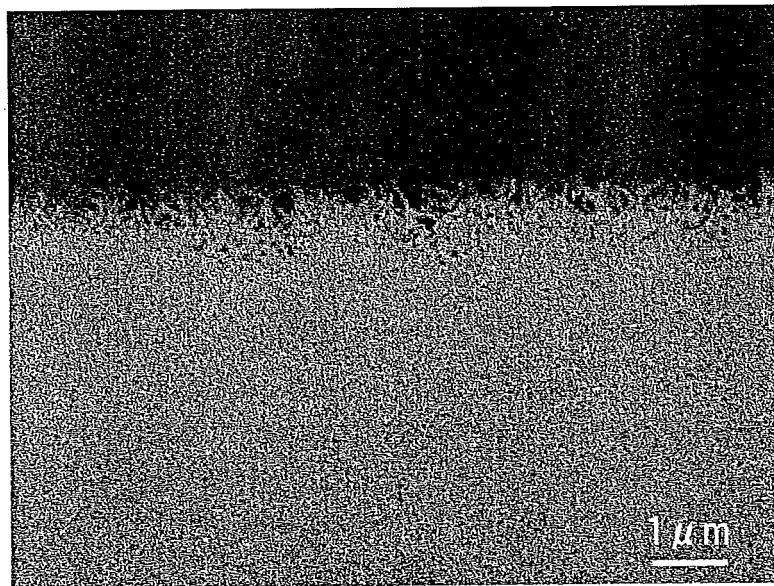


FIG. 7

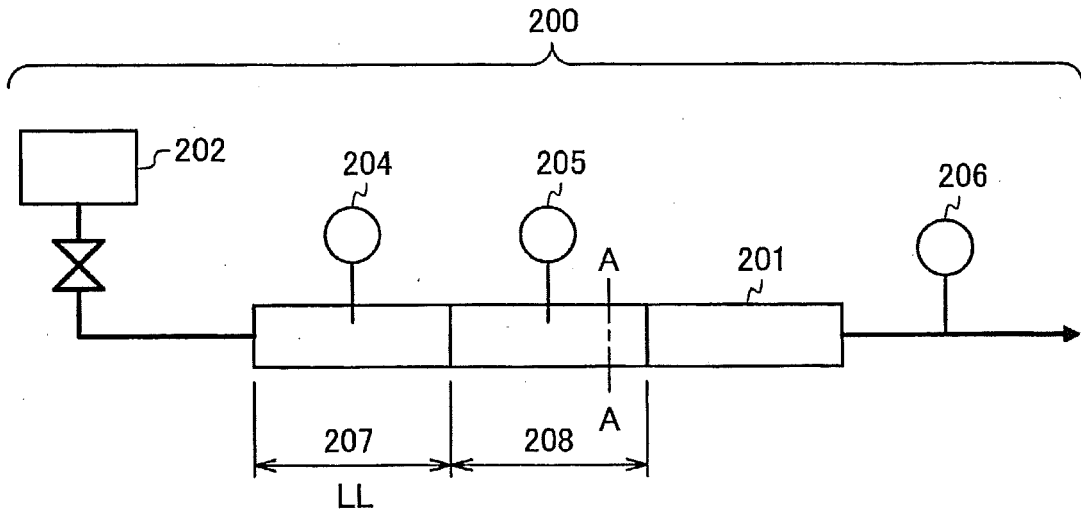
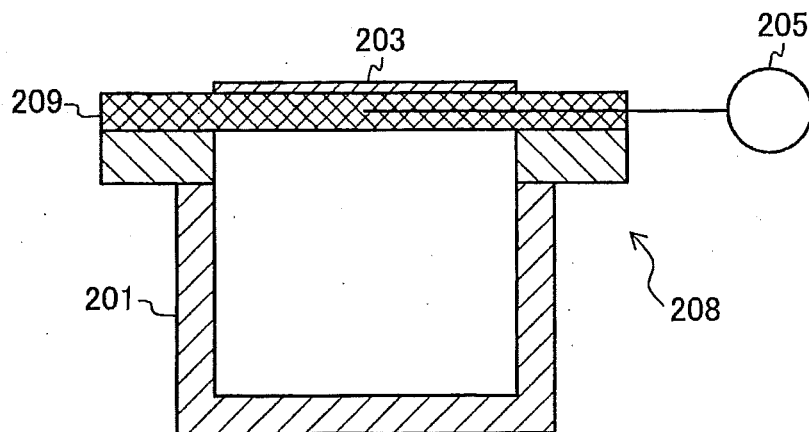


FIG. 8



## INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2013/063859

## A. CLASSIFICATION OF SUBJECT MATTER

F28F9/24(2006.01)i, F25B39/00(2006.01)i, F28F1/32(2006.01)i, F28F1/40  
(2006.01)i, F28F13/02(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)  
F28F9/24, F25B39/00, F28F1/32, F28F1/40, F28F13/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2013  
Kokai Jitsuyo Shinan Koho 1971-2013 Toroku Jitsuyo Shinan Koho 1994-2013

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

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	JP 10-026491 A (Kao Corp.), 27 January 1998 (27.01.1998), paragraphs [0002], [0008] to [0013], [0068] to [0070], [0083]; fig. 1 (Family: none)	1, 3-5 2, 6, 7
Y	JP 2011-185543 A (Toyota Motor Corp.), 22 September 2011 (22.09.2011), paragraphs [0051] to [0053]; fig. 7 (Family: none)	2
Y	JP 2009-18280 A (Kobe Steel, Ltd.), 29 January 2009 (29.01.2009), paragraphs [0007] to [0023], [0092] (Family: none)	6

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

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"E" earlier application or patent but published on or after the international filing date	"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
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search  
07 August, 2013 (07.08.13)

Date of mailing of the international search report  
20 August, 2013 (20.08.13)

Name and mailing address of the ISA/  
Japanese Patent Office

Authorized officer

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## INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2013/063859

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

5	Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	Y	JP 11-211376 A (Mitsubishi Materials Corp.), 06 August 1999 (06.08.1999), claims 1, 3 (Family: none)	7
10	A	JP 2003-001746 A (Hitachi, Ltd.), 08 January 2003 (08.01.2003), entire text; all drawings (Family: none)	1-7
15	A	JP 2003-293166 A (Kobe Steel, Ltd.), 15 October 2003 (15.10.2003), entire text; all drawings (Family: none)	1-7
20	A	WO 2010/143564 A1 (Kobe Steel, Ltd.), 16 December 2010 (16.12.2010), entire text; all drawings & US 2012/0077055 A1 & EP 2442059 A1 & CN 102460057 A & KR 10-2012-0024719 A	1-7
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**REFERENCES CITED IN THE DESCRIPTION**

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