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(71) Applicant: **Mitsubishi Electric Corporation**
Tokyo 100-8310 (JP)

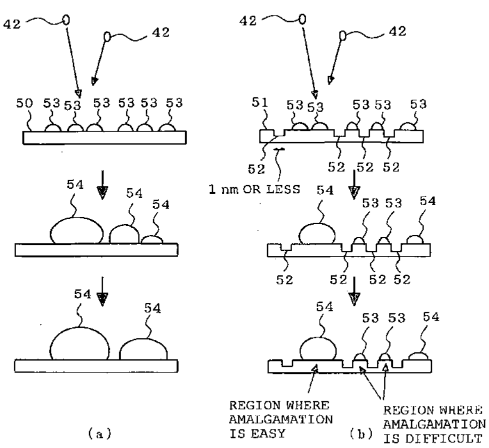
(72) Inventors:
- **TASHIRO, Yusuke**
Tokyo
1008310 (JP)
- **HAMADA, Mamoru**
Tokyo
1008310 (JP)
- **UNEZAKI, Fumitake**
Tokyo 100-8310 (JP)
- **MAEGAWA, Takeyuki**
Tokyo 100-8310 (JP)
- **MORIMOTO, Hiroyuki**
Tokyo 100-8310 (JP)
- **YAMASHITA, Kouji**
Tokyo 100-8310 (JP)

(74) Representative: **Gleiter, Hermann**
Pfenning, Meinig & Partner GbR
Patent- und Rechtsanwälte
Theresienhöhe 13
80339 München (DE)

(54) HEAT EXCHANGER AND REFRIGERATING CYCLE DEVICE PROVIDED WITH SAME

(57) In an outdoor unit in a cold area and an indoor unit of a refrigerating device, a temperature of a heat exchanger functioning as an evaporator is cooled up to an air dew-point temperature or below, and when the temperature is 0°C or below, a frost formation phenomenon occurs on a surface. The frost formation causes increase in air-path resistance and thermal resistance and leads to reduced ability of the device. However, if the frost formation can be delayed, energy saving can be realized. Thus, by providing a plurality of holes, for example, a plurality of holes whose radius is an order of several nanometers on the fin surface of the heat exchanger, generation of condensed water droplets on the fin surface is suppressed. By providing a plurality of holes exerting the Gibbs-Thomson effect so as to lower the freezing point, reduced ability due to the frost formation is delayed.

FIG. 6



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Description

Technical Field

[0001] The present invention relates to a heat exchanger disposed in an air conditioner, low-temperature equipment, water heating equipment and the like, for performing heat exchange with air. The present invention particularly relates to a technology in which a region of frost formed on a heat transfer face and a formation temperature are controlled, and even if frost is formed on the heat transfer face, time until an air path becomes clogged is delayed, and device performance can be maintained for a long time by providing a plurality of holes in the heat transfer face with air of a fin constituting the heat exchanger.

Background Art

[0002] In a prior-art refrigerating cycle system, if a surface temperature of a fin constituting a heat transfer face of a heat exchanger used therein falls to 0°C or below, a phenomenon called frost formation occurs in which water vapor in the air is condensed on the fin surface so as to become water droplets, which subsequently cooled to form ice droplets and become frost as a result.
[0003] If frost is formed on the fin surface, the thicker the frost becomes, the greater heat resistance on the fin surface is raised, and as a result, a heat exchange amount with air is decreased, which leads to deterioration of the device performance.
[0004] If the frost further grows, a gap between the fins becomes clogged, an air path resistance is increased, and the device performance is largely deteriorated.
[0005] Also, in order to eliminate the frost adhered to the fin surface, the device needs a periodical defrosting, which also markedly deteriorates the device performances.
[0006] In order to cope with this frost formation problem, there has been a technique of frost formation delay in which plasma irradiation to the fin surface is performed so as to make the fin surface super hydrophilic and to improve a water discharge property by hydrophilic treatment (See Patent Document 1, for example).
[0007]

[Patent Document 1] Japanese Unexamined Patent Application Publication No. 2002-90084 (Figs. 2, 4)

Disclosure of Invention

Problems to be Solved by the Invention

[0008] As mentioned above, in a general prior art heat exchanger, heat resistance and air path resistance become large due to frost formation, and it has a problem of performance deterioration when frost is formed.
[0009] Also, with the heat exchanger disclosed in Patent Document 1, if the heat exchanger is not hydrophilic to frost formation, the frost formation delaying effect cannot be exerted, and a surface state should be maintained over a long time so as to keep hydrophilic properties.
[0010] The present invention pays attention to the following two phase changes in a formation process of frost, which will be described later:

(1) phase change from water vapor to condensed water droplets; and
(2) phase change from condensed water droplets to ice droplets,
and by providing a large number of holes in a fin of the heat exchanger, a frost formation area is to be restricted and a condensation temperature is to be lowered so that the performance is maintained for a long time even if frost is formed and to promote energy saving.

[0011] A radius of the holes to be provided in the fin is of nanosize, and since it is sufficiently smaller than a diameter of dust and dirt usually presumed to be present indoors and outdoors, the hole is not clogged and the performance can be maintained over a long time.

Means for Solving the Problems

[0012] A heat exchanger according to the present invention restricts a region where condensed water droplets are generated by providing holes on a surface of a fin for heat transfer constituting the heat exchanger and by setting a radius of the holes to be smaller than a critical radius of the condensed water droplets (or condensed liquid droplets)

determined by an air condition and a surface temperature of the fin.
Also, a hole that creates the Gibbs-Thomson effect is provided on the surface of the fin for heat transfer constituting the heat exchanger so that a freezing point of the condensed water droplets (or condensed liquid droplets) is lowered to 0°C or below in the hole.
Also, holes are provided only on one side of each of the fins for heat transfer arranged in plural in parallel constituting the heat exchanger so as to delay the time required for clogging between the fins due to a frost layer and further to shorten the time required for defrosting.

Effect of the Invention

[0013] According to the heat exchanger of the present invention, on the fin surface, actions such that a frost formation range is narrowed, a frost formation amount is reduced, and frost formation is delayed, are generated, and performance can be maintained even if the frost is formed, and energy saving can be promoted.

Brief Description of the Drawings

[0014]

[Fig. 1] Fig. 1 is a configuration diagram of a refrigerating cycle device illustrating an embodiment 1 of the present invention.
[Fig. 2] Fig. 2 is a perspective view of an evaporator (heat exchanger) illustrating the embodiment 1 of the present invention.
[Fig. 3] Fig. 3 is a schematic diagram illustrating a formation process of condensed water droplets.
[Fig. 4] Fig. 4 is a graph illustrating a radius r dependency of a nucleus of an formula (1).
[Fig. 5] Fig. 5 is a graph illustrating a critical radius r* dependency of a nucleus of pressure ratio.
[Fig. 6] Fig. 6 is a schematic diagram illustrating a process in which condensed water droplets are formed on a surface having holes and a surface without a hole.
[Fig. 7] Fig. 7(a) is an explanatory diagram illustrating a frost formation state onto a fin in a prior art. Fig. 7(b) is a schematic diagram illustrating a fin of the evaporator (heat exchanger) of the embodiment 1.
[Fig. 8] Fig. 8 (a) is a temperature distribution diagram in the vicinity of a heat transfer pipe of the fin of the evaporator (heat exchanger). Fig. 8 (b) and 8 (c) are schematic diagrams illustrating a fin configuration example 1 (b) and a fin configuration example 2 (c) according to an embodiment 2 of the present invention, respectively.
[Fig. 9] Fig. 9 is a graph illustrating a critical radius r* dependency of freezing point depression.
[Fig. 10] Fig. 10 is a diagram illustrating a behavior of condensed water droplets at a position having a hole and a position without a hole on the fin surface.
[Fig. 11] Fig. 11 is an outline view illustrating opposing fins of the evaporator (heat exchanger) showing an embodiment 3 of the present invention.
[Fig. 12] Fig. 12 is a schematic diagram of the fin of the evaporator (heat exchanger) illustrating an embodiment 4 of the present invention.
[Fig. 13] Fig. 13 is a schematic diagram of the fin having slits illustrating the embodiment 4 of the present invention.

Reference Numerals

[0015]

11 outdoor unit
12 indoor unit
21 compressor
22 condenser (heat exchanger)
23 fan for condenser
24 expanding means
25 evaporator (heat exchanger)
26 fan for evaporator
31 fin
32 heat transfer pipe
41 surface on cooling face
42 water vapor
43 nucleus

44 condensed water droplet
45 condensed water droplet after amalgamation
46 ice droplet
47 needle-like frost
50 untreated fin surface
51 fin surface having a hole with a radius of not more than 1 nm on the surface
52 hole with a radius of not more than 1 nm
53 nucleus
54 condensed water droplet
61 fin
62 heat transfer pipe
63 hole of not more than critical radius r* in embodiment 1
64 frost
71 fin surface
72 heat transfer pipe
73 hole offered for freezing point depression of condensed water droplet by Gibbs-Thomson effect
81 fin surface
83 hole offered for freezing point depression of condensed water droplet by Gibbs-Thomson effect
84 condensed water droplet
91 fin
92 slit

Best Modes for Carrying Out the Invention

Embodiment 1

[0016] An embodiment 1 of a heat exchanger according to the present invention will be described using a refrigerating cycle device in which the heat exchanger is used as an example, referring to the attached drawings. Fig. 1 shows a refrigerant circuit of a refrigerating device. This refrigerating device is a device used for refrigerating indoors by carrying out a vapor compression type refrigerating cycle operation. In Fig. 1, reference numeral 11 denotes an outdoor unit and reference numeral 12 denotes an indoor unit. The outdoor unit 11 is provided with a compressor 21, a condenser 22, and a fan 23 for the condenser for feeding air into the condenser 22, and the indoor unit 12 is provided with expanding means 24, an evaporator 25, and a fan 26 for the evaporator for feeding air into the evaporator 25. The compressor 21, the condenser 22, the expanding means 24, and the evaporator 25 constitute a refrigerating cycle circuit, and a refrigerant for circulation is filled therein. This device is of a form mainly found in low-temperature equipment such as a unit cooler and a showcase.

[0017] The refrigerant inside the refrigerating device is compressed by the compressor 21 to become of a high temperature and high pressure and flows into the condenser 22. Then, the refrigerant radiates heat in the condenser 22 to become a liquid refrigerant and then, it is expanded by the expanding means 24 to become a gas / liquid two-phase refrigerant. The refrigerant absorbs heat from ambient air in the evaporator 25, becomes a gas and returns to the compressor 21. Therefore, the refrigerating cycle device carries out a cooling operation for cooling an inside air.

[0018] Fig. 2 shows details of the evaporator 25 shown in Fig. 1. The evaporator 25 shown in Fig. 2 is a fin-tubular heat exchanger widely used for refrigerating devices and air conditioners. The condenser 25 is mainly constituted by a plurality of fins (heat transfer fins) 31 and a plurality of heat transfer pipes 32. The plurality of fins 31 are stacked with a predetermined interval therebetween, and the heat transfer pipes 32 are provided so as to penetrate through holes provided in each fin 31. The condenser 25 absorbs heat by evaporation of the liquid refrigerant flowing in through the heat transfer pipes 32 and carries out heat exchange with the outside air through the fins 31. Aluminum plate and the like which is easy to be processed and has good thermal conductivity is suitable for the fins 31. In order to perform an efficient heat exchange process with air, as shown by an arrow in Fig. 2, air is fed into the evaporator 25 toward the fins 31 in parallel from an evaporator fan 26.

[0019] For example, while under a cold storage condition, an ambient temperature is 0°C and an evaporation temperature of the refrigerant is approximately -10°C, under a refrigerating condition, the ambient temperature is -20°C and the evaporation temperature is approximately -30°C. Under such conditions, the surfaces of the fins 31 are 0°C or below for both cases, and frost is formed on the fins 31. If frost is formed, an air volume flowing through the evaporator 25 is reduced, a heat exchange amount with the air is lowered, and the cooling performance of the evaporator is deteriorated.

[0020] From the above, if an amount of the frost generated on the fins 31 can be reduced, air path resistance caused by a frost layer can be decreased. Then, in the embodiment 1, holes with a radius derived from the following formulas (1) to (4) are provided on the fin 31 so as to decrease the frost amount and to reduce the frost height. By delaying the time to the clogging of the air path, the performance deterioration of the device is suppressed even if frost is formed.

[0021] Next, the process of frost formation will be described in detail. Here, a generation / growing process of the frost will be described using Fig. 3. When the air of a temperature 0°C or above is in contact with a cooled surface 41, and the surface temperature is cooled up to the dew-point temperature or below determined by the temperature and humidity of the air, water vapor 42 in the air is cooled on the surface 41 and condensed into nuclei 43 on the surface 41 so that condensed water droplets 44 are formed. On the surface 41 which is not treated, this condensation may occur everywhere. The condensed water droplets 44 amalgamate with adjacent condensed water droplets 44 to lower surface energy and continue growing. Since this amalgamation occurs at random, there are condensed water droplets 45 having different diameters on the surface 41. When the temperature on the surface 41 falls to 0°C or below, the condensed water droplets are cooled to 0°C or below and condensed to become ice droplets 46. From the ice droplets 46, frost 47 is generated in a needle state and a frost layer is formed as the whole.

[0022] If the air temperature is 0°C or below, it has been reported in the literature that frost is formed by sublimation, but it has also been reported that over-cooled liquid water exists up to -40°C. However, essentially, the frost formation process is not different from that of 0°C or above. The condensed water droplets or ice droplets formed on the cooled surface amalgamate together, the needle-like frost is generated from the ice droplets, and the frost layer is formed as a whole.

[0023] The above growth process from water vapor to frost is generated by two phase changes. One is a phase change from water vapor to the condensed water droplets, while the other is the phase change from the condensed water droplets to ice droplets. In the phase change, nuclei are generated in a stable environment phase, and growth of the nuclei leads to formation of a different phase. For the nuclei to grow, the free energy G of the entire phase needs to be lowered thermodynamically, and its change amount dG is given by the following formula (1) when a nucleus with a radius r is generated:

[0024]

$$dG = -(4\pi r^3/3v)d\mu + 4\pi r^2\gamma \ \dots \ (1)$$

[0025] Where, v denotes the volume of one molecule, dμ denotes a change amount of chemical potential per molecule, and γ denotes the surface energy density. When G is lowered by the growth of the nucleus, r is increased so that dG is decreased. The r dependency of formula (1) is shown in Fig. 4. The vertical axis in Fig. 4 represents a value of dG, and the horizontal axis a radius r of the nucleus. The first term on the right-hand side is decreased to be negative with an increase of r, and the second term is increased to be positive with the increase of r. From Fig. 4, the formula (1) has a local maximum value at a certain r = r*, and dG is increased with the increase of r at 0 < r < r*, while at r > r*, dG is decreased with the increase of r. That is, only the nucleus with the radius r being not less than r* can continue growing. This r is referred to as a critical radius r*, and r* can be acquired by differentiating the formula (1) by r and is given by the following formula (2).

[0026]

$$r^* = 2\gamma v \ / \ d\mu \ \dots \ (2)$$

[0027] Next, control of the phase change from water vapor to condensed water droplets will be described. Here, a case is examined where the above formation process is from water vapor to condensed droplets. When considering a change in the gas phase, dμ in the formula (2) is given by the following formula (3) using a pressure in each phase:

[0028]

$$d\mu = kT\log(p/pe) \ \dots \ (3)$$

[0029] Where, k denotes the Boltsmann constant, T denotes a temperature of the fin surface (or a temperature of condensed water droplets), p denotes water vapor pressure, and pe denotes an equilibrium vapor pressure of the condensed water droplets.

[0030] By substituting the formula (3) into the formula (2), the following formula (4) is acquired:

[0031]

$$p/pe = \exp((2\gamma v)/(kTr^*)) \ldots (4)$$

[0032] Fig. 5 is a diagram illustrating p/pe as a function of r* when the condensed water droplets are assumed to be 0°C. Where, γ = 76 [erg/cm^2] and v = 3 $\times$ 10^{-23} [cm^3] (physical property values of water at 0°C) are used. A value of the r* dependency of p/pe shown in Fig. 3 does not largely change even if T is changed (even if T = 263,283 [K], for example). That is, the phase change from the water vapor to the condensed water droplets can be examined by this diagram.

[0033] For example, when the air conditions are temperature 7°C, relative humidity 85%, and the fin surface temperature -10°C, the difference in the frost growing process is shown using Fig. 6 between a fin surface 51 (Fig. 6B) in which holes 52 are provided on the surface and a surface 50 (Fig. 6A) without holes. When the temperature is 7°C and the relative humidity is 65%, water vapor pressure in the air is p = 854 [Pa]. Since the temperature of the condensed water droplets is considered to be -10°C, which is almost equal to the surface temperature, the equilibrium vapor pressure of the condensed water droplets at -10°C is pe = 286 Pa, and p is approximately 3 times of pe. Under the above conditions, the critical radius r* is r* = 1 nm from Fig. 5. That is, a nucleus 53 with r > 1 nm can grow. Therefore, as shown in Figs. 6A and 6B, the nucleus 53 with r > 1 nm continues growing, amalgamates with an adjacent condensed water droplet to become a larger water droplet 54. On the other hand, if the hole 52 with the radius of less than 1 nm is opened on the surface, since a condensed water droplet with a radius of more than 1 nm cannot be formed inside the hole 52, a condensed water droplet is not generated inside the hole 52, and there will be a region where the water droplets can be easily amalgamated and a region otherwise on the surface as shown in Fig. 6B. As a result, as shown in Fig. 6B, amalgamation of the condensed water droplets is suppressed on the fin surface 51 on which the holes 52 are opened, the frost formation amount is reduced compared with the untreated surface 50, and the frost height is also lowered.

[0034] A reference value of the diameter of the hole 52 is changed in accordance with a state in which the device is to be used. However, if the hole radius is too small, the above effect cannot be expected unless countless number of holes are provided on the fin surface. If a hole with a radius of approximately 0.5 nm or more is opened, it can be used for current air conditioners and refrigerators.

[0035] The diameter of the hole provided on the fin is of nanosize and since it is sufficiently smaller than the diameter of dirt, dust and the like usually presumed to be present indoors and outdoors, the hole does not become clogged and the performance is maintained over a long time.

[0036] The depth of the hole provided in the fin does not preferably penetrate the fin in view of strength of the actual fin. Methods of opening a hole of nanoorder in the fin include an anodization method. In the anodization method, a metal is treated as an anode, an insoluble electrode is made to be a cathode and a direct-current electrolysis operation is conducted in an electrolytic solution. When the anode and cathode are electrified, a surface of the anode metal is oxidized, and a part of the metal is ionized to be dissolved into the electrolytic solution. In particular, aluminum, niobium, tantalum and the like are given an oxidized film by the anodization method. Since the oxidized film has poor electric conductivity, as the anodization processing progresses, a metal oxide is formed on a base metal, and a thin hole structure grown regularly is formed. A depth of the thin hole is determined by the time during which a voltage is applied, but it is preferable the depth be such that the hole does not penetrate the fin as mentioned above. Also, since the oxidized film also has a poor heat conductivity, which deteriorates heat exchange between the surface and the air, it is not necessarily favorable to open a deep hole. However, the above effect is not essentially changed for a penetrated hole. For a heat exchanger having an extremely thin fin, a penetrated hole may be opened.

[0037] As mentioned above, by providing a hole smaller than the critical radius determined by the air conditions and the fin surface (cooled face) temperature condition on an upwind side of the fin, the condensed water droplets can be generated only in a region other than the holes on the fin surface, the frost formation amount on the fin can be reduced, and the frost height can be lowered. With this arrangement, even if the air passes on the upwind side, the water vapor is not condensed but flows to a downwind side. As a result, clogging of the fin can be delayed, and performance deterioration caused by the frost formation can be delayed. Also, by using this effect, an interval between the fins can be further narrowed so that a small-sized heat exchanger with good performance can be obtained.

[0038] Also, in order to increase the heat exchange amount with the air in an evaporator (heat exchanger) used in an air conditioner, for example, the fin interval is made narrower than that of the general heat exchanger. Thus, as shown in Fig. 7A, when the upwind side and the downwind side are compared, an amount of frost 64 formed on the upwind side is larger, and the height of the frost 64 is higher on the upwind side and becomes lower toward the downwind side. That is because since most of the water vapor in the air becomes condensed water droplets in the upwind side, the water vapor amount contained in the air decreases toward the downwind side. For such a heat exchanger, by decreasing the frost formation amount on the upwind side, the height of the frost formed on the upwind side can be lowered, and by having the frost formed uniformly on the entire fin, the time to an air path clogging can be delayed. Therefore, as shown in Fig. 7B, by providing a hole 63 of not more than the above-mentioned critical radius r* on the upwind side of the fin 61, the frost amount formed on the upwind side can be decreased, and the height of the frost formed on the upwind side can be lowered. Reference numeral 62 in Fig. 7 denotes a heat transfer pipe.

Embodiment 2

[0039] Next, a heat exchanger of an embodiment 2 of the present invention will be described. Fig. 8 shows a fin 71 and a heat transfer pipe 72 constituting the evaporator (heat exchanger) 25. As having been already described, the condenser (heat exchanger) 25 conducts heat absorption by evaporating a liquid refrigerant flowing in through the heat transfer pipe 72 to heat exchange with the outside air through the fin 71. As mentioned above, the refrigerating conditions are the ambient air temperature of -20°C, the evaporation temperature of about -30°C, and the fin 71 surface becomes 0°C or below to cause frost formation. Also, as shown in Fig. 8, the periphery of the heat transfer pipe 72 can be considered to particularly have a low temperature on the fin 71 surface. In the embodiment 2, by providing holes 73 offered for dropping the freezing point of the condensed water droplets by the Gibbs-Thomson effect in the following formulas (5), (6) on the entire fin 71 or around the heat transfer pipe 72, time to the frost formation is delayed, and performance deterioration of the device is suppressed.

[0040] Next, control of the phase change from condensed water droplets to ice droplets will be described. Consider a case that the phase generation process shown in the embodiment 1 is from the condensed water droplet to the ice droplets.
When considering the change in a melt liquid phase, $d\mu$ is given by the following formula (5) using a temperature T of a liquid phase.

[0041]

$$d\mu = L(Tm - T) / Tm \ldots (5)$$

[0042] Where, L denotes a latent heat of melting, and Tm a freezing temperature.

[0043] By substituting the formula (5) for the formula (2), the following formula (6) is obtained:

[0044]

$$Tm - T = (2\gamma v Tm/L) \cdot (1/r^*) \ldots (6)$$

[0045] The left-hand side of the formula (6) represents a temperature difference between the freezing temperature and the liquid phase.

[0046] Fig. 9 is a diagram illustrating the r* dependency of Tm - T of water. Tm = 273 [K] and L = 9.97×10^{-14} [erg] (physical values of water) are used. From Fig. 9, when r* is sufficiently large, Tm - T is asymptotic to 0, and the liquid phase temperature corresponds to Tm. This is a state of freezing found in a bulk system. On the other hand, with the decrease of r*, Tm - T increases. That is, the smaller r* is, Tm does not become a freezing point and freezing point depression occurs. This effect is called the Gibbs-Thomson effect.

[0047] As shown in Fig. 10, for example, consider a case in which a large number of holes 83, each having the radius of 10 nm, are opened on a surface 81. If the hole 83 is filled with a condensed water droplet 84, the radius of the condensed water droplet 84 can be considered to be 10 nm. Then, the freezing temperature of the condensed water droplet 84 in the hole 83 is known from Fig. 9 to be close to -15°C. Then, even if the surface 81 is cooled to -10°C, the condensed water droplet 84 in the hole 83 is not frozen but become the ice droplet 85 only in a region other than the hole 83. As a result, the frost formation amount is reduced. That is, in the hole with the radius of r* in the formula (6), the freezing point of the condensed water droplet in the hole becomes 0°C or below. By providing the holes 83 having the Gibbs-Thomson effect on the entire fin, the clogging time caused by frost formation is delayed. Also, by providing a large number of such holes 83 around the heat transfer pipe of the evaporator (heat exchanger), condensed water droplets to become ice droplets around the heat transfer pipe are decreased. When the device is operated at a low temperature at 0°C or below, the frost formation amount around the heat transfer pipe can be reduced.
An interval between the holes 83 is preferably an interval of approximately in the order of several nm, which is equal to the hole diameter, and at least 200 holes 83 are needed on a plane of 200 nm $\times$ 200 nm, so that an optimal effect cannot be expected with the number of holes of approximately 50.

[0048] By providing the holes 83 having the above effect on the fin, reduction of the frost formation amount can be expected. As a result, even in the case of operation with a temperature of the evaporator to become lower, the time to clogging between the fins can be delayed, which leads to performance improvement of the device and energy saving.

[0049] The diameter of the hole 83 provided on the fin is of nanosize, and since it is sufficiently smaller than the diameter of dirt, dust and the like usually presumed to be present indoors and outdoors, the holes are not clogged, and the performance is maintained over a long time.

Embodiment 3

[0050] Next, the configuration of an embodiment 3 of the present invention will be described. Fig. 11 shows an example of a well-known configuration of an evaporator (heat exchanger). In this evaporator (heat exchanger), a plurality of the fins 31 are arranged in parallel with a predetermined interval, and the heat transfer pipes 32 penetrate them. In such a heat exchanger, when the fins 31 are cooled to 0°C or below and frost formation begins, the frost grows from both faces of the opposing fins 31. After some time elapsed, the gap between the fins 31 becomes clogged by the frost, the fins 31 are buried, and the performance of the evaporator is deteriorated. Therefore, defrosting is carried out for the evaporator so as to defrost the frost between the fins 31. A general defrosting method is to switch a four-way valve so as to reverse the direction of a refrigerant flow and to switch an evaporator heat exchanger and a condenser heat exchanger for defrosting.

[0051] Though special treatment is not applied to the surface of the fin 31 in the prior art fins, in the embodiment 3, the holes 52, 63, 73, 83 described in the embodiment 1 or the embodiment 2 are provided on the entire surface of only on one face of the opposing fins 31. The frost grows on one face of the fin 31 through the above-mentioned process, but on the face with the holes 52, 63, 73, 83, the condensed water droplets are hard to be generated on the entire fin 31, the freezing point is further lowered, and the growth of the frost is delayed more than on the untreated face. As a result, the time to the air path clogging can be prolonged.

[0052] In the prior art fins, almost the same amount of frost adheres to both of the opposing fins 31, but the fin 31 having the holes on one face described in the embodiment 1 or the embodiment 2 supports the frost only by one face. Therefore, the frost can easily drop in defrosting, and time required for defrosting is shortened, which contributes to energy saving.

[0053] The diameter of the hole provided on the fin is of nanosize, and since it is sufficiently smaller than the diameter of dirt, dust and the like usually presumed to be present indoors and outdoors, the hole is not clogged and the performances are maintained over a long time.

Embodiment 4

[0054] Moreover, a configuration of an embodiment 4 of the present invention will be described. Fig. 12 shows the heat transfer fin 31 of the condenser (heat exchanger) shown in the embodiment 1. As mentioned above, the fins 31 are arranged in plural in parallel with a predetermined interval, and when the fins 31 are cooled to 0°C or below, the frost formation begins. Then, the gap between the fins 31 becomes clogged by the frost, the fins 31 are buried, and the performance of the device is deteriorated.

[0055] Although no hole is provided on the surface of the prior art fin, in the embodiment 4, the holes 52, 63, 73, 83 described in the embodiment 1 or the embodiment 2 are provided in plural rows arranged in parallel with a wind direction in the fin 31. With this arrangement, even if the gap between the fins 31 is clogged, a passage for wind is ensured, and drop in wind velocity can be delayed.

Thereby, the holes to be provided on the fin 31 are preferably arranged close together with a small pitch or located close to each other in plural rows. This applies not only to the embodiment 4 but also to other embodiments.

[0056] As mentioned above, by providing the holes 52, 63, 73, 83 of nanosize on the fins, it is found that a frost formation delay effect can be obtained. Also, it is effective to provide the above holes in the heat exchanger having a slit in the fin so that the heat exchange with air can be performed efficiently. As shown in the upper stage in Fig. 13, for example, a slit fin has a slit 92 on a fin 91 in order to positively perform heat exchange with the air. However, a generation amount of condensed water droplets in the slit 92 portion is large and the frost formation amount also becomes large. When the amount of frost is increased, the effect of the slit 92 is lost. In order to reduce the frost formation in the slit 92 portion, as shown in the lower stage of Fig. 13, by intensively providing the holes 52, 63, 73, 83 in the slit 92 portion, the frost formation in the slit 92 portion is reduced, and the effect of the slit 92 can be maintained for a long time.

[0057] Types of the heat exchanger to which the present invention can be applied are not limited to those described above, but also to a heat exchanger having a corrugated fin used in an automobile, for example.

[0058] Thanks to the present invention, condensed water droplets of water vapor in the air generated on the fin surface can be generated only in a specific area, and the frost formation amount generated on the fin surface can be decreased. Also, by providing the holes 52, 63, 73, 83 on the upwind side of the fin, the frost layer on the fin surface has an almost constant height with respect to an travelling direction of the wind. As a result, air path resistance is reduced, performance at the frost formation is improved, and energy saving can be promoted.

Also, since the freezing point of the condensed water droplets in the holes 73, 83 are lowered by the Gibbs-Thomson effect, by providing such holes 73, 83 on the entire fin, frost formation on the fin is delayed when the heat exchanger is

operated at a low temperature of 0°C or below.
Similarly, by intensively providing the holes 52, 63, 73, 83 around the heat transfer pipe of the fin, thermal resistance can be reduced, and performance deterioration can be delayed when the heat exchanger is operated at a low temperature of 0°C or below.
Moreover, by providing the above-mentioned holes only on one face of the fin, the frost growth can be limited only to one face of the fin, the time required for a gap between the fins to become clogged can be delayed, and moreover, when defrosting, the frost can be easily peeled off the fin, and time required for defrosting is shortened.

[0059] The diameter of the holes provided on the fin is of nanosize, and since it is sufficiently smaller than the diameter of dirt, dust and the like usually presumed to be present indoors and outdoors, no hole is clogged and the performances are maintained over a long time.

Industrial Applicability

[0060] By utilizing the present invention, the problem of frost formation can be solved on the surface of the heat exchanger for heat exchange with air at 0°C or below. Particularly, in the refrigerating cycle system, the air-path clogging is caused by frost formation in the heat exchanger, which results in performance deterioration such as thermal resistance and defrosting. However, thanks to the present invention, the time to the air path clogging can be prolonged, performance deterioration of the heat exchanger can be delayed, and energy can be also saved.

Claims

1. A heat exchanger provided with a heat transfer pipe through which a fluid passes and a heat transfer fin which said heat transfer pipe penetrates and carries out heat exchange with air, wherein
a plurality of holes having a radius smaller than a critical radius r* of a condensed water droplet determined by an air temperature and an air humidity around said heat transfer fin and a surface temperature of said heat transfer fin are provided on a surface of said heat transfer fin.

2. The heat exchanger of claim 1, wherein
said critical radius r* has a relation of $p/pe = \exp((2\gamma v) / (kTr^*))$,
where p is a water vapor pressure, pe is an equilibrium vapor pressure of the condensed water droplet, γ is surface energy density, v is a volume of a single molecule, k is the Boltsmann constant, and T is a surface temperature of the heat transfer fin.

3. A heat exchanger provided with a heat transfer pipe through which a fluid passes and a heat transfer fin which said heat transfer pipe penetrates and carries out heat exchange with air, wherein
a plurality of holes having a radius smaller than a radius r* given by, $Tm - T = (2\gamma vTm/L)\cdot(1/r^*)$, are provided in plural on a surface of said heat transfer fin,
where γ is surface energy density, v is a volume of a single molecule, Tm is a freezing temperature, L is latent heat of melting, and T is a surface temperature of the heat transfer fin.

4. The heat exchanger of any one of claims 1 to 3, wherein said holes are provided only on one face of said heat transfer fin.

5. The heat exchanger of any one of claims 1 to 3, wherein said heat transfer fin having a slit on a surface thereof has said hole provided in the vicinity of said slit.

6. The heat exchanger of any one of claims 1 to 3, wherein said holes are provided in a region on an upwind side of said heat transfer fin.

7. The heat exchanger of any one of claims 1 to 3, wherein said holes are provided around said heat transfer pipe of said heat transfer fin.

8. The heat exchanger of any one of claims 1 to 3, wherein said holes are provided in a row in parallel with an air passage direction.

9. The heat exchanger of any one of claims 1 to 8, wherein said holes provided in said heat transfer fin are arranged with a small pitch in a closely collected state or in plural rows close to each other.

10. A refrigerating cycle device provided with the heat exchanger of any one of claims 1 to 9 as an evaporator.

FIG. 1

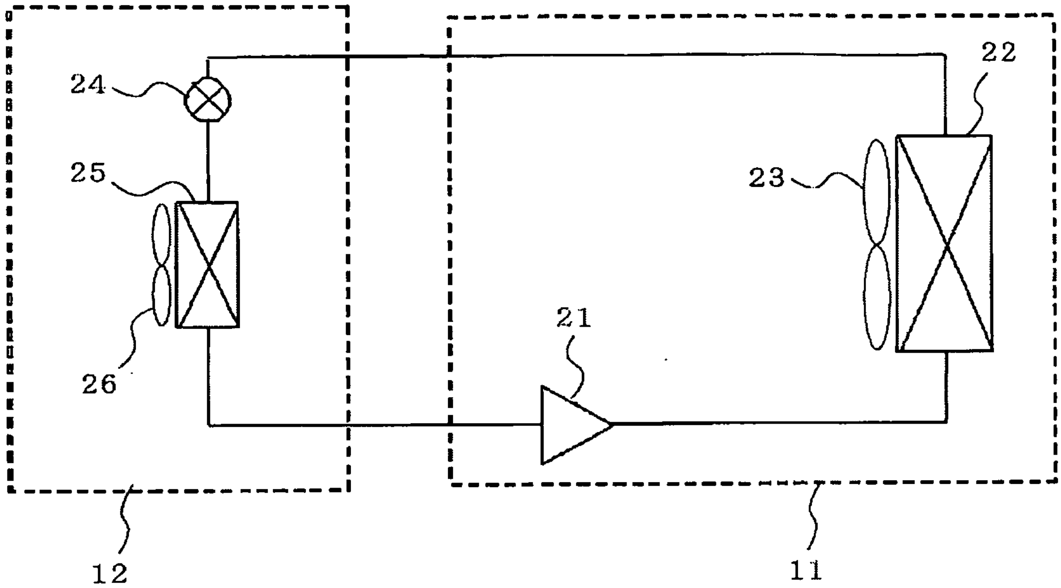
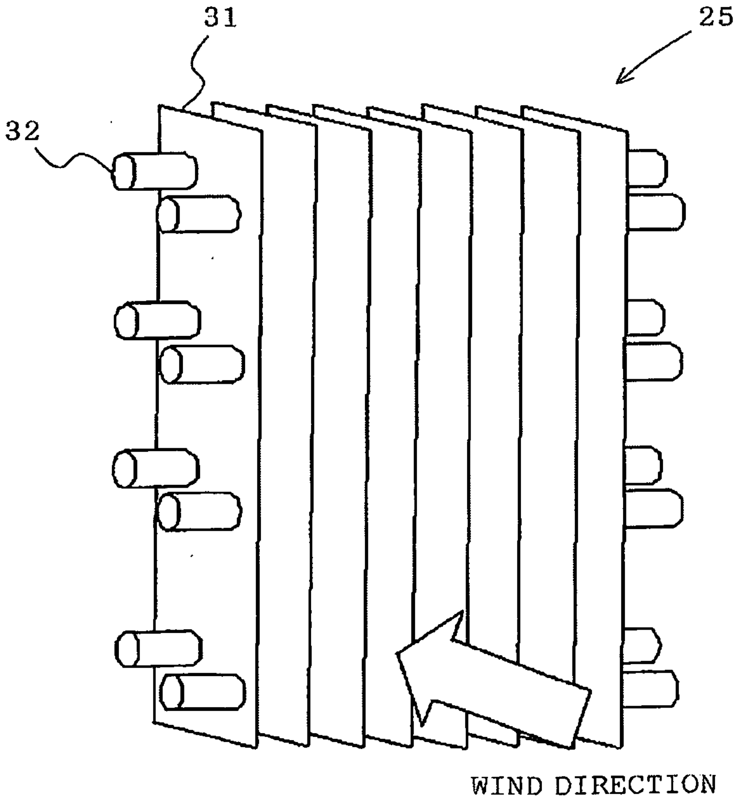
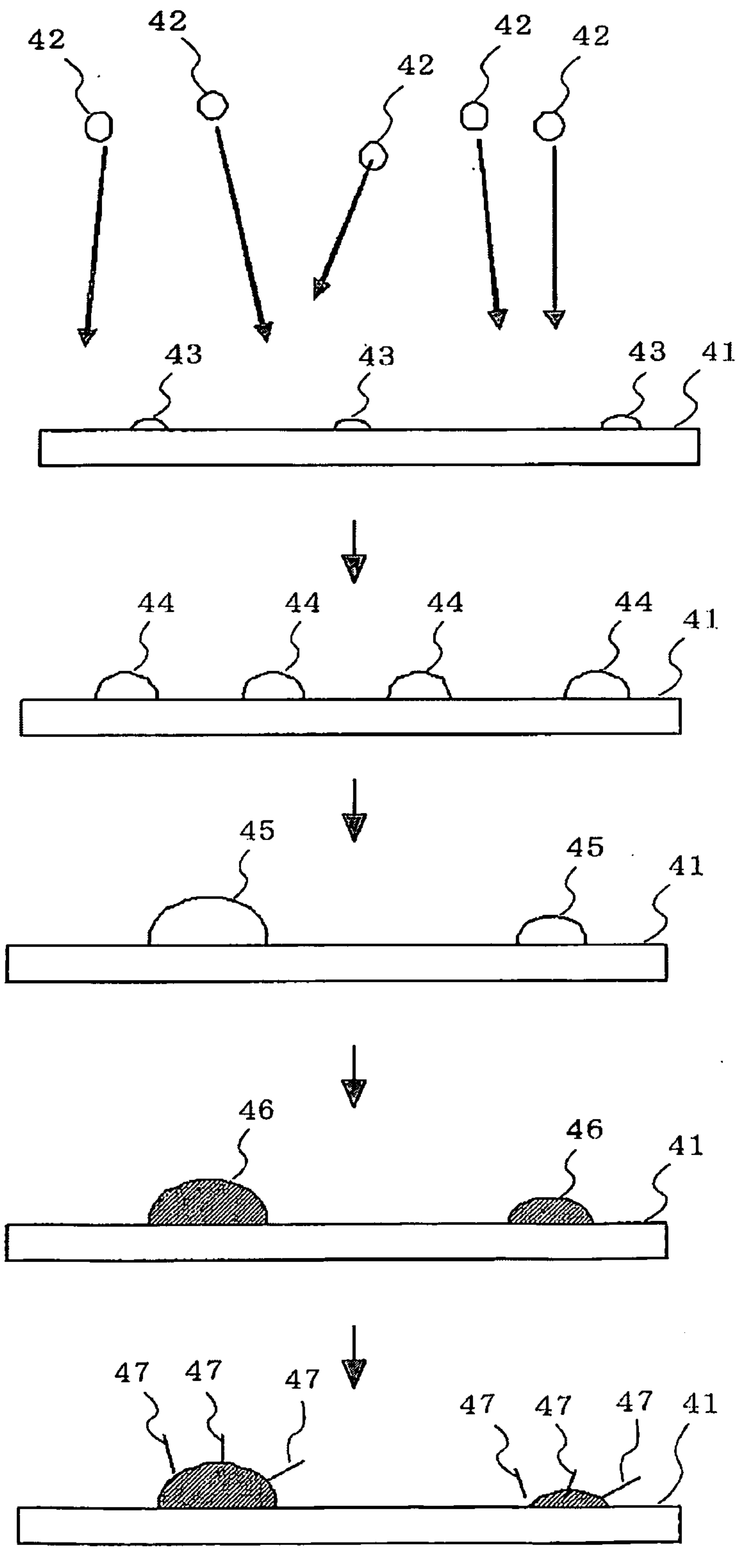


FIG. 2



F I G. 3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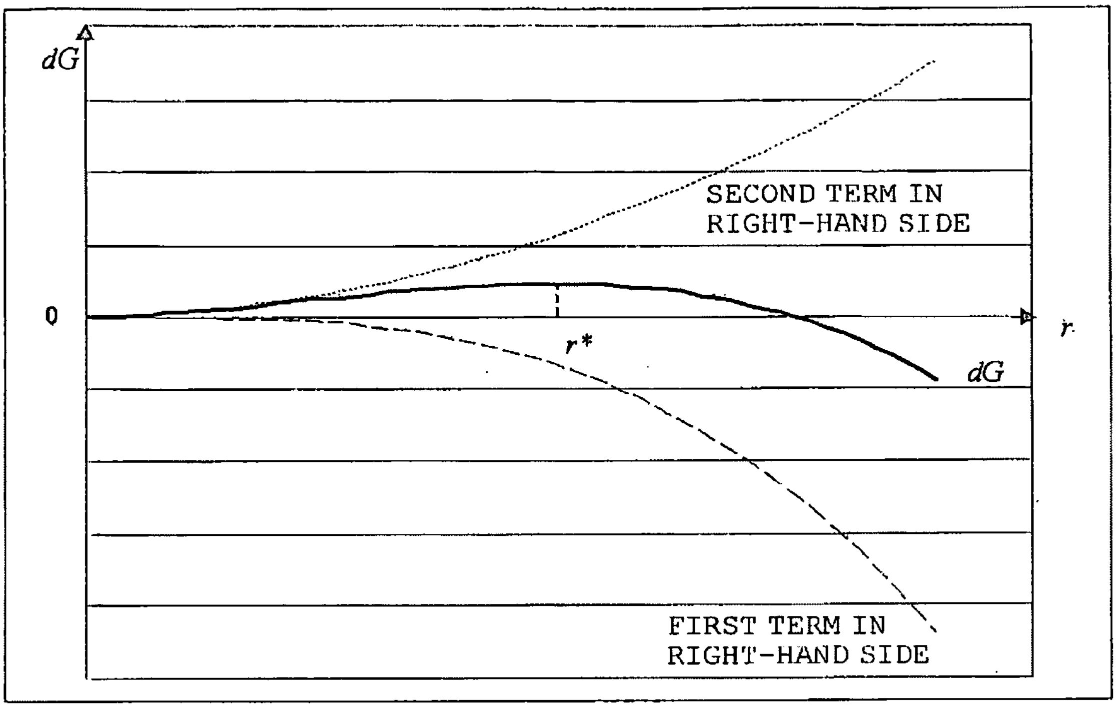
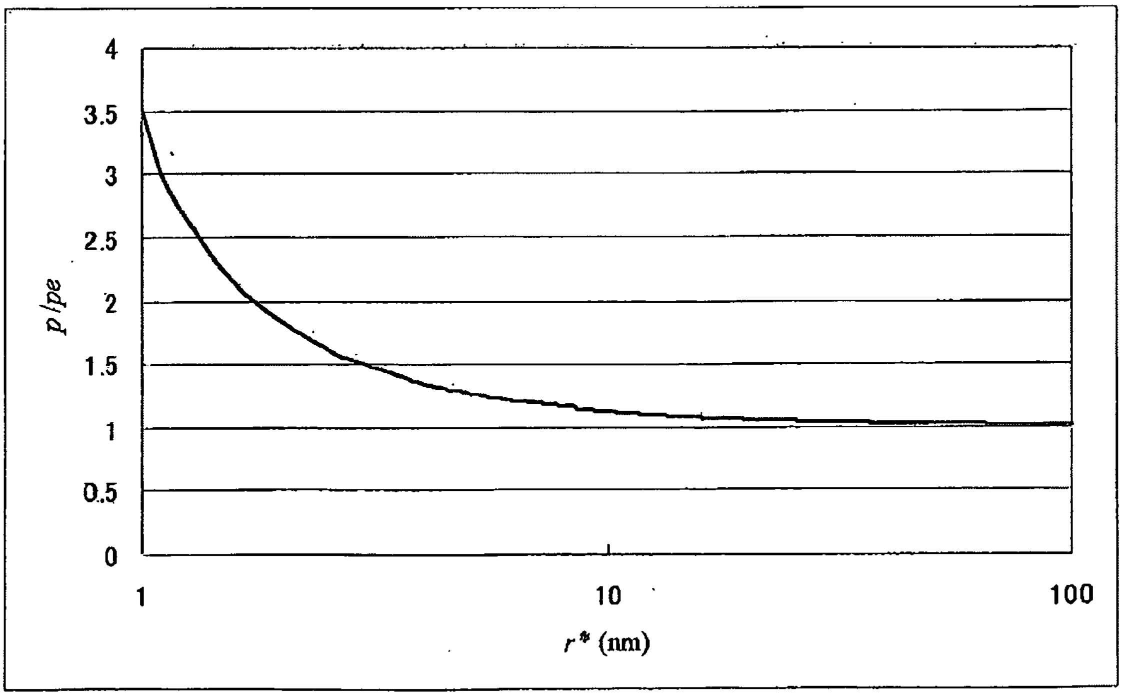
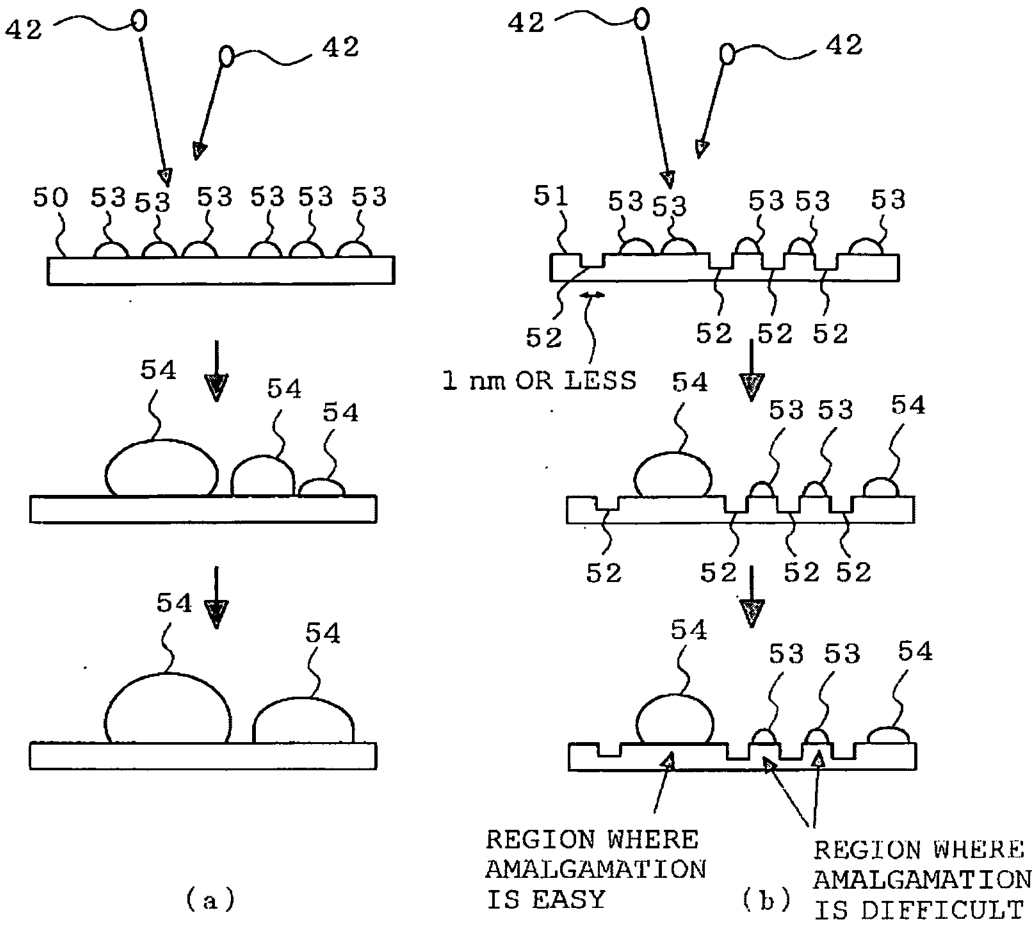
F I G. 4


dG
0
r
r*
dG
SECOND TERM IN
RIGHT-HAND SIDE
FIRST TERM IN
RIGHT-HAND SIDE

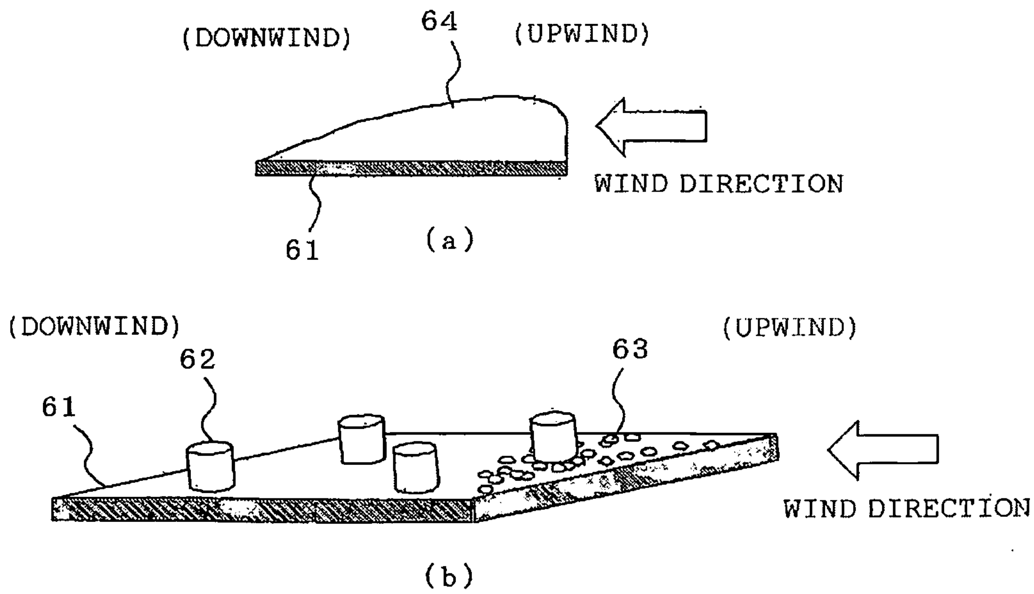
F I G. 5


4
3.5
3
2.5
2
1.5
1
0.5
0
p/pe
1
10
100
r* (nm)

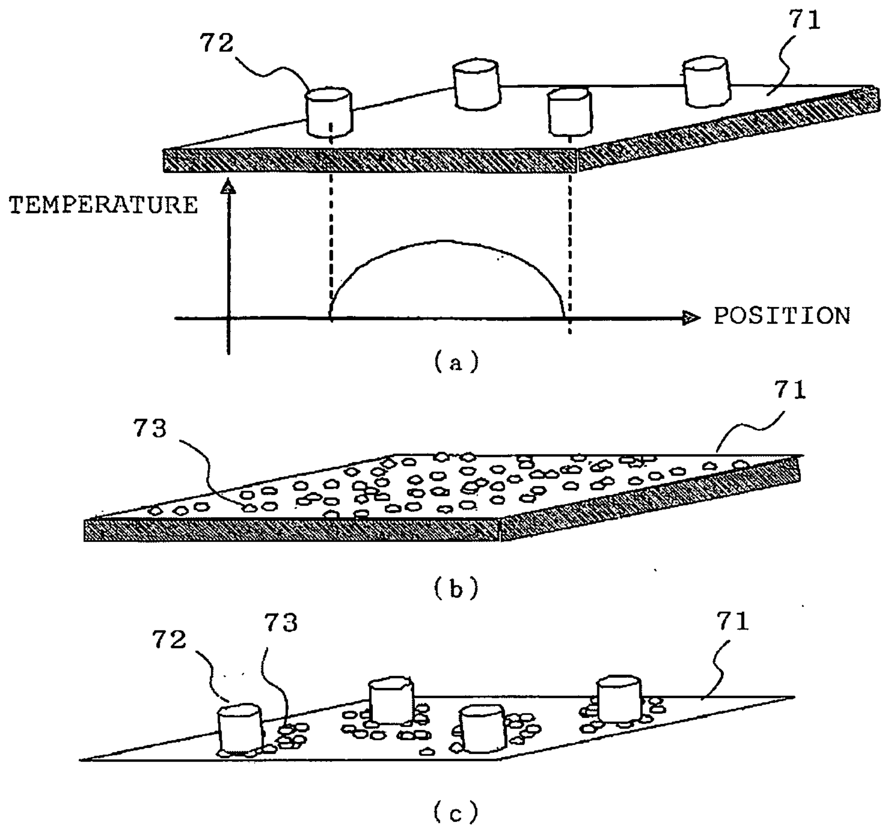
F I G. 6


42
42
50
53
53
53
53
53
53
54
54
54
54
54
(a)
42
42
51
53
53
53
53
53
52
52
52
52
1 nm OR LESS
54
53 53
54
52
52
52
52
54
53 53
54
REGION WHERE
AMALGAMATION
IS EASY
REGION WHERE
AMALGAMATION
IS DIFFICULT
(b)

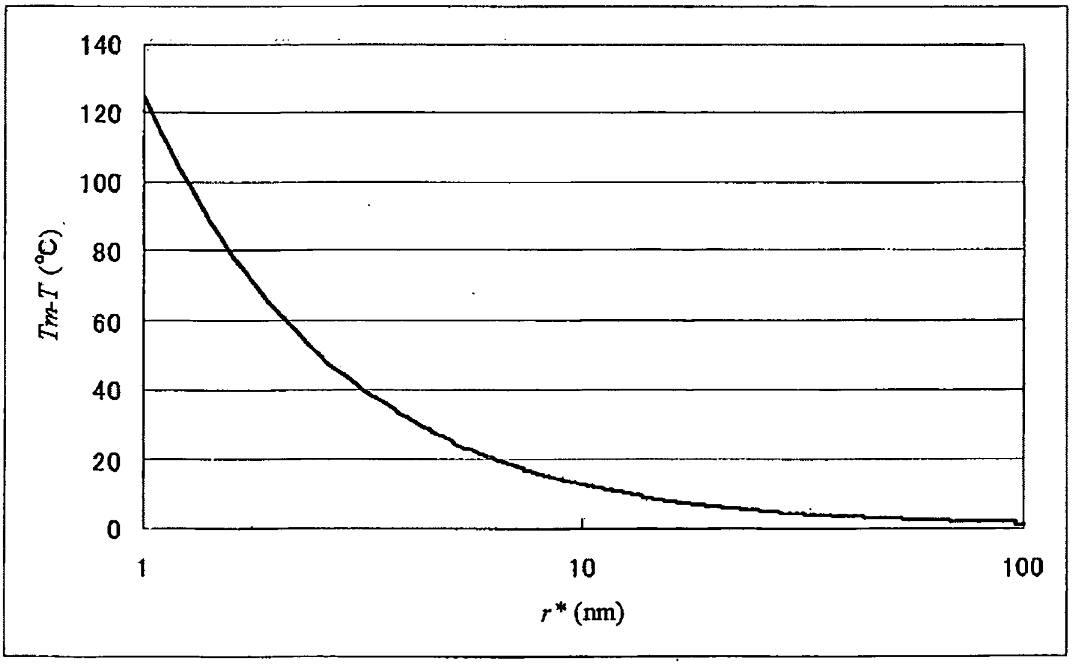
F I G. 7


(DOWNWIND)
64
(UPWIND)
WIND DIRECTION
61
(a)
(DOWNWIND)
(UPWIND)
62
63
61
WIND DIRECTION
(b)

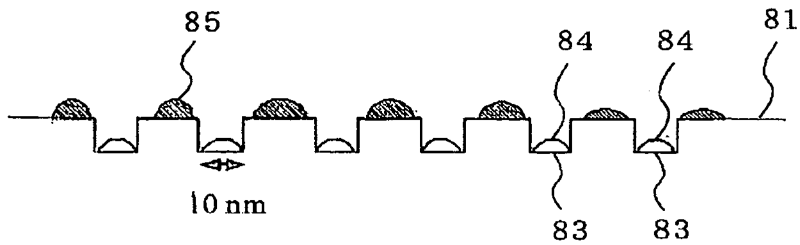
F I G. 8


72
71
TEMPERATURE
POSITION
(a)
73
71
(b)
72
73
71
(c)

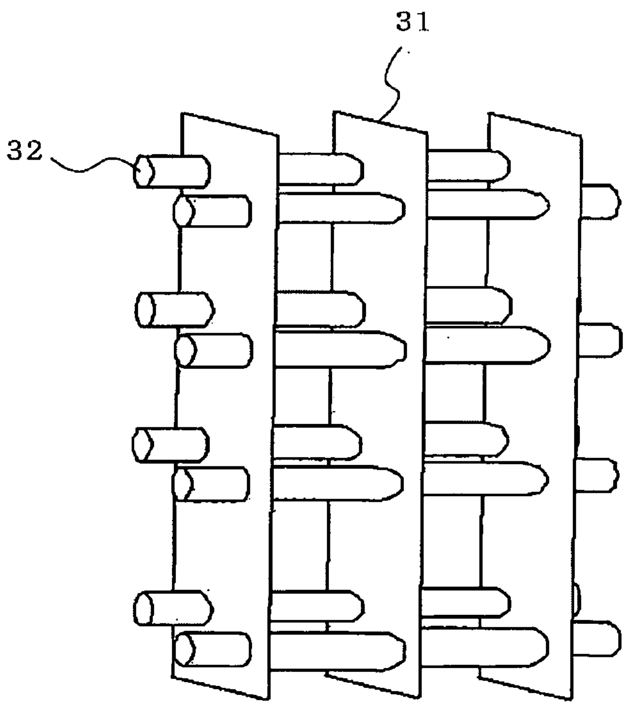
F I G. 9


140
120
100
80
60
40
20
0
Tm-T (℃)
1
10
100
r* (nm)

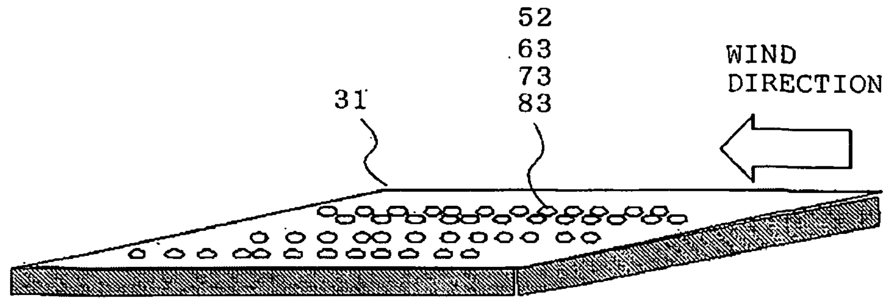
F I G. 1 0



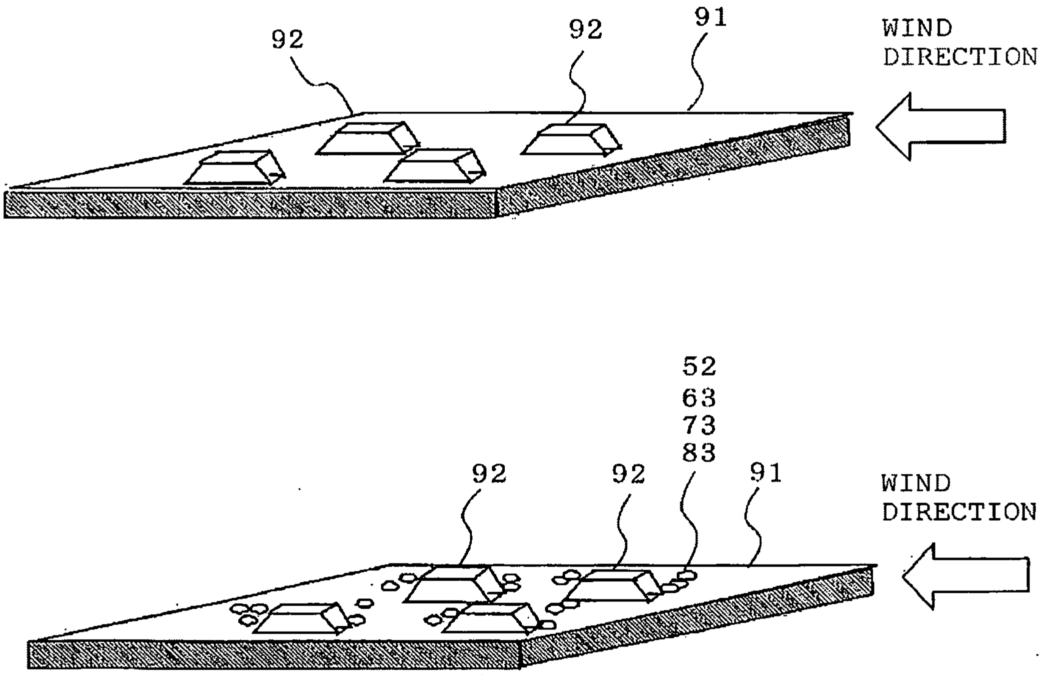
F I G. 1 1



F I G. 1 2


52
63
73
83
31
WIND
DIRECTION

F I G. 1 3


92
92
91
WIND
DIRECTION
52
63
73
83
92
92
91
WIND
DIRECTION

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2009/055585

A. CLASSIFICATION OF SUBJECT MATTER
F28F1/32(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F28F1/32

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	1996-2009
Kokai Jitsuyo Shinan Koho	1971-2009	Toroku Jitsuyo Shinan Koho	1994-2009

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 2002-90084 A (Daikin Industries, Ltd.), 27 March, 2002 (27.03.02), Full text; all drawings (Family: none)	1 2-10
Y	JP 2000-356440 A (Ishikawajima-Harima Heavy Industries Co., Ltd.), 26 December, 2000 (26.12.00), Par. Nos. [0048] to [0055]; Fig. 4 (Family: none)	2-10

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

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Date of the actual completion of the international search	Date of mailing of the international search report
07 May, 2009 (07.05.09)	19 May, 2009 (19.05.09)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (April 2007)

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Patent documents cited in the description

- JP 2002090084 A **[0007]**