



(11) **EP 1 795 848 A1**

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 158(3) EPC

(43) Date of publication:
13.06.2007 Bulletin 2007/24

(51) Int Cl.:
F28F 1/02 (2006.01) **F28D 1/053** (2006.01)
F28F 1/32 (2006.01)

(21) Application number: **05781541.7**

(86) International application number:
PCT/JP2005/015940

(22) Date of filing: **31.08.2005**

(87) International publication number:
WO 2006/025465 (09.03.2006 Gazette 2006/10)

(84) Designated Contracting States:
**AT BE BG CH CY CZ DE DK EE ES FI FR GB GR
HU IE IS IT LI LT LU LV MC NL PL PT RO SE SI
SK TR**

• **KAWATSU, Yasuhiro,**
c/o GAC CORPORATION
Nagano 3998286 (JP)

(30) Priority: **31.08.2004 JP 2004252671**

(71) Applicant: **Gac Corporation**
Nagano 399-8286 (JP)

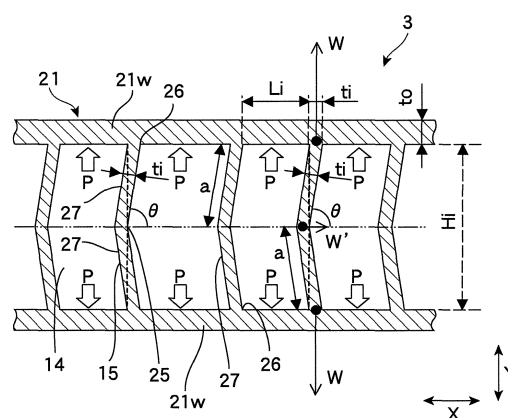
(74) Representative: **Körber, Martin Hans**
Mitscherlich & Partner
Patentanwälte
Sonnenstrasse 33
80331 München (DE)

(72) Inventors:
• **MAEZAWA, Takahide,**
c/o GAC CORPORATION
Nagano 3998286 (JP)

(54) **FLAT PERFORATED PIPE AND HEAT EXCHANGER**

(57) There is provided a multi-channeled flat tube that includes a flat outer tube and a plurality of partitions that divide the inside of the outer tube into a plurality of channels. Each partition in the multi-channeled flat tube has a mountain-shaped cross-sectional form composed of two sides, each of the two sides has a thickness t_i and a length α , the partitions are disposed so that a face-to-face distance between adjacent partitions along inner surfaces of the outer tube is Li , and a thickness to of the outer tube satisfies a condition below. By selecting an appropriate pressure when expanding the multi-channeled flat tube, it is possible to prevent deformation of the tube outer surface into a wavy or undulating pattern

Fig. 6



$$\sqrt{\frac{Li \cdot ti \cdot \sqrt{a^2 - ti^2}}{3a}} \leq to .$$

Description

TECHNICAL FIELD

5 [0001] The present invention relates to the construction of a multi-channeled flat tube used in a heat exchanger.

BACKGROUND ART

10 [0002] A plate-fin heat exchanger equipped with a plurality of plate fins disposed in parallel at regular intervals and a plurality of tubes disposed so as to pass through such fins is known as one example of a heat exchanger used in refrigeration apparatuses, radiators, and the like. One method of manufacturing a plate-fin heat exchanger includes passing the tubes through the fins to assemble, and expanding or enlarging the tubes to join the tubes and fins together. In the expanding the tubes, a rigid rod or a tube expander is inserted into the tubes to press out and widen the tubes from the inside. By expanding the tubes, the tubes and fins are brought into contact.

15 [0003] The use of multi-channeled flat tubes (multi-channel flat tubes) in heat exchangers is also known. A multi-channeled flat tube includes a plurality of partitions provided inside of the tube to divide the inside of the tube into a plurality of parallel channels.

20 [0004] Japanese Laid-Open Patent Publication No. S62-19691 discloses a tube with an oval or rectangular cross-section. By expanding the surface of the tube bridging between pairs of joints, the tube surface is pressed onto cooling fins. When the tube (wall of tube) expands outward, the joints deform from their original "mountain" shapes (chevron shapes) to flat shapes, thereby preventing the wall of the tube from contracting or shrinking to their original positions.

DISCLOSURE OF THE INVENTION

25 [0005] One aspect of the present invention is a multi-channeled flat tube including: a flat outer tube; and a plurality of partitions that divide an inside of the outer tube into a plurality of channels. Each of the plurality of partitions has a chevron (mountain-shaped) cross-sectional form composed of two sides. Each of the two sides has a thickness t_i and a length α . The plurality of partitions are disposed so that a face-to-face distance between adjacent partitions of the plurality of partitions along inner surfaces of the outer tube is L_i . In addition, a thickness t_o of the outer tube satisfies Condition (1)

30 below

Equation 1

35

$$\sqrt{\frac{L_i \cdot t_i \cdot \sqrt{a^2 - t_i^2}}{3a}} \leq t_o \quad \dots(1).$$

40 [0006] One method of expanding tube is inserting tube expanders into channels of a multi-channeled flat tube. Aside from this method, research has been conducted into introducing a fluid into a multi-channeled flat tube to raise the internal pressure and thereby extend the partitions. Regardless of whether a method that raises the internal pressure of the tube (hereinafter referred to as "pressurized tube expansion") or expansion using tube expanders is carried out, it is not preferable for the outer tubes located between adjacent partitions (hereinafter referred to as "outer walls") to expand outward so that the tube outer surface deforms into a wavy or undulating form. This would reduce the contact surface area between the tube outer surface and the fins and reduce the heat transfer performance. However, if tube expansion is stopped before the partitions have extended to reach the desired size, the desired performance cannot be obtained.

50 [0007] When examining how partitions that are bent into "mountain" shapes (chevron shapes, defined here as the shape of the Japanese hiragana character "Ku" (equivalent to a V shape)) become extended, the tensile stress that acts from both ends of each partition first causes the partition to deform so that the angle between both sides that construct the mountain shape (the V shape) opens up (i.e., the angle increases). After this, once the angle between the two sides has reached a certain magnitude, deformation of the partition that further increases the angle (i.e., deformation that changes the inclination of the partition, "angle deformation") largely ceases and the inclination of the partition stops changing (i.e., the partition becomes straightened out). Hereafter, the tensile stress that acts from both ends of the partition causes deformation (hereinafter, "stretch deformation") that reduces the thickness of the partition. The amount of stress that changes the inclination of a partition differs to the amount of stress that causes stretch deformation of the

55

partition and makes the partition thinner, with less stress being required to change the inclination of the partition.

[0008] With a multi-channeled flat tube with an outer tube whose thickness satisfies Condition (1) given above, the outer walls at parts of the outer tube between partitions will not deform in a range of pressure that is high enough to change the inclination of the partitions. Accordingly, a multi-channeled flat tube that satisfies Condition (1) described above can prevent deformation in the outer walls until the partitions have become straightened out. This means that by using an internal pressure in a range where there is deformation in the inclination of the partitions, the multi-channeled flat tube can be expanded in a state where deformation in the tube outer surface into a wavy or undulating state is prevented.

[0009] The amount of deformation in the inclination of the partitions varies due to the influence of tolerances for the multi-channeled flat tube and fluctuations in the applied pressure. This means that the tube should preferably be expanded with a maximum pressure (internal pressure) in the range where deformation occurs in the inclination of the partitions, or a higher pressure. By expanding the tube with such pressure, it is possible to expand a tube until a state where the inclined partitions become substantially straightened out. Accordingly, during expansion, it is possible to expand the multi-channeled flat tube to a desired state without having to carry out control of the pressure varying step-by-step. If the thickness t_o of the outer tube is small so that the thickness t_o of the outer tube is outside the range of Condition (1), there is the possibility of deformation occurring in the outer tube before the partitions have become straightened out. Accordingly, pressure control during tube expansion becomes difficult.

[0010] Another aspect of this invention is a heat exchanger that includes: a plurality of multi-channeled flat tubes that satisfy Condition (1); and a plurality of fins that are attached to the multi-channeled flat tubes. It is preferable that the plurality of multi-channeled flat tubes pass through the plurality of fins. As described earlier, with a multi-channeled flat tube that satisfies Condition (1), regardless of whether pressurized tube expansion is carried out using a fluid or whether the tube is expanded using tube expanders, it will be possible to extend the partitions while suppressing deformation in the outer walls. This means that it is possible to raise the contact efficiency after tube expansion between the plurality of multi-channeled flat tubes and the plate fins through which the tubes pass and to which the tubes are attached. Accordingly, it is possible to raise the heat transfer efficiency of the heat exchanger. In particular, when using pressurized tube expansion using a fluid, it is not necessary to insert a tube expander, which makes this method suited to expanding all of the narrow channels of the multi-channeled flat tubes substantially uniformly.

[0011] One of other aspects of the present invention is a multi-channeled flat tube where in addition to Condition (1) above, the thickness t_o of the outer tube also satisfies Condition (2) below

Equation 2

$$2\sqrt{\frac{L_i \cdot t_i \cdot \sqrt{a^2 - t_i^2}}{3a}} \geq t_o \quad \dots(2).$$

[0012] Here, in terms of making products smaller and lighter, it would not be economic to increase the thickness of the outer tube of a multi-channeled flat tube that includes a plurality of partitions to the thickness of an outer tube required for a flat tube not equipped with partitions. One merit of using multi-channeled flat tubes is that since the flat tubes can be made sufficiently strong by providing partitions inside the tube, it is possible to reduce the thickness of the outer walls or outer tube.

[0013] Further one of other aspects of the present invention is a multi-channeled flat tube where in addition to Condition (1) above, the thickness t_o of the outer tube also satisfies Condition (3) below

Equation 3

$$\sqrt{\frac{L_i \cdot t_i}{2}} \geq t_o \quad \dots(3).$$

[0014] A pressure that is equal to or greater than the pressure used during tube expansion is not a normal operating pressure of a multi-channeled flat tube. If such pressure were applied during normal operation, there would be the possibility of further deformation in the multi-channeled flat tube since this is not how multi-channeled flat tubes are designed. Accordingly, the pressure used during tube expansion is an upper limit of the withstand pressure conditions

for normal operation or even higher. Also, the pressure used during tube expansion is set up to at a pressure whereby the partitions become straightened out and is not set at a pressure whereby stretch deformation of partitions, which makes the partitions thinner, commences. This means it is economical to set the thickness of the outer tubes so that the outer walls deform at a pressure where stretch deformation, which makes the partitions thinner, commences. The heat transfer efficiency also increasing when thin outer tubes are used.

[0015] In addition, with multi-channeled flat tubes that satisfy Condition (3), if excessive internal pressure that would cause stretch deformation of the partitions is applied during pressurized tube expansion, there is the possibility of the outer walls also expanding, resulting in the tube outer surfaces deforming. Accordingly, the state of the tube outer surfaces can also serve as one factor used when checking the pressure during tube expansion.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016]

FIG. 1 schematically shows a heat exchanger.

FIG. 2 shows a state where multi-channeled flat tubes and fins of the heat exchanger shown in FIG. 1 have been joined together.

FIG. 3(a) shows a cross section in a length direction of the multi-channeled flat tubes before tube expansion and

FIG. 3(b) shows a cross section of one of the multi-channeled flat tubes in a minor axis direction.

FIG. 4(a) shows a cross section in the length direction of the multi-channeled flat tubes after tube expansion, FIG.

4(b) shows a cross section in the minor axis direction of an end part of one of the multi-channeled flat tubes, and

FIG. 4(c) shows a cross section in the minor axis direction of another part of such multi-channeled flat tube.

FIG. 5(a) shows "angle deformation" of partitions and FIG. 5(b) shows "stretch deformation" of the partitions.

FIG. 6 shows an enlargement of a cross section of a multi-channeled flat tube.

FIG. 7 shows changes in the inner diameter of a multi-channeled flat tube when the internal pressure has been raised.

FIG. 8 shows how fluctuations occur in the amount by which the multi-channeled flat tubes expand due to tolerances and the like.

FIG. 9 shows examples of an upper limit and a lower limit for the thickness of the outer tube of a multi-channeled flat tube.

BEST MODE FOR CARRYING OUT THE INVENTION

[0017] FIG. 1 schematically shows a heat exchanger that uses multi-channeled flat tubes. FIG. 2 is a perspective view showing an enlargement of a state where the multi-channeled flat tubes have been expanded. The heat exchanger 1 is a plate fin-type heat exchanger. The heat exchanger 1 has a plurality of plate-like fins 2 disposed in parallel at regular intervals and a plurality of multi-channeled flat tubes 3 that are disposed in parallel and are joined to the fins 2 in a state where the multi-channeled flat tubes 3 pass through the fins 2. Each multi-channeled flat tube (flat multi-channeled tube, multi-channel flat tube) 3 is constructed so that the inside of a flat outer tube 21 is divided into a plurality of parallel channels 14 by a plurality of partitions 15. End parts 4 at both ends of the multi-channeled flat tubes 3 are connected to joining holes 19 formed in side walls 9 of headers 6 and 7 positioned on the left and right sides of the heat exchanger 1. A heat transfer medium (internal fluid) introduced from a supply outlet 11 of the header 6 passes through the channels 14 of the multi-channeled flat tubes 3 and is guided or led to an output outlet 12 of the header 7. When an external fluid B such as air passes over the heat exchanger 1, the external fluid B contacts the multi-channeled flat tubes 3 and the fins 2, heat exchange occurs between the heat transfer medium and the external fluid so that the heat transfer medium and/or the external fluid is cooled or heated.

[0018] FIG. 3(a) shows the multi-channeled flat tubes 3 before the tubes have been expanded. When manufacturing the heat exchanger 1, the multi-channeled flat tubes 3 are inserted into burring holes 18 provided in advance in the fins 2 to provisionally assemble the fins 2 and the multi-channeled flat tubes 3 together.

[0019] FIG. 3(b) shows an enlargement of the cross-section of a multi-channeled flat tube 3. The outer tube 21 of the multi-channeled flat tube 3 includes outer walls 21w that oppose each other at the top and bottom of the multi-channeled flat tube 3. The multi-channeled flat tube 3 is a flat tube molded so that the outer wall 21w that forms the upper wall or top wall of the outer tube 21 and the outer wall 21w that forms the lower wall or bottom wall are substantially parallel. A plurality of partitions 15 that connect the upper and lower outer walls 21w and respectively have cross-section bent like "mountain"-shaped (V-shaped) to the length direction X of the cross-section of the multi-channeled flat tube 3 are provided inside each multi-channeled flat tube 3. These partitions 15 divide the inside of the flat tube 3 to form the plurality of parallel channels 14.

[0020] The end parts 4 of the multi-channeled flat tubes 3 that have been assembled so as to pass through the fins 2 are inserted into the joining holes 19 provided in the headers 6 and 7. These end parts 4 are joined to the headers 6

and 7 by brazing or another suitable method. By doing so, the parallel flow channels 14 of the individual flat tubes 3 are connected via the headers 6 and 7 and form internal paths through which the heat transfer medium flows.

[0021] FIGS. 4(a), 4(b), and 4(c) are cross-sectional views showing the state of the multi-channelled flat tubes 3 after pressurized tube expansion. FIGS. 5(a) and 5(b) show how the partitions 15 of the multi-channelled flat tubes 3 are straightened. A compressed fluid can be supplied via the headers 6 and 7 to the multi-channelled flat tubes 3. The compressed fluid raises the internal pressure of the parallel channels 14 and can expand multi-channelled flat tubes 3 (pressurized tube expansion). By expanding the tubes 3, as shown in FIG. 4(a), the multi-channelled flat tubes 3 and the respective fins 2 are tightly joined. With the heat exchanger 1, the headers 6 and 7 are joined to the end parts 4 of the multi-channelled flat tubes 3 in advance. This means that as shown in FIG. 4(b), the bent partitions 15 are not straightened at the end parts 4 of the tubes 3. At other parts, including the parts where the multi-channelled flat tubes 3 pass through the fins 2, the bent partitions 15 are straightened as shown in FIG. 4(c).

[0022] Each of the partitions 15 of the multi-channelled flat tubes 3 that is used in the heat exchanger 1 has a thickness t_i and each side out of the two sides forming the mountain shape has a length α . The gap (face-to-face distance (distance between surfaces)) between the partitions (adjacent partitions) 15 along the inner surfaces of the outer walls 21w of the flat outer tube 21 is the distance L_i . The thickness t_i of the outer tube 21 satisfies Equation (1) below.

Equation 1

$$\sqrt{\frac{L_i \cdot t_i \cdot \sqrt{a^2 - t_i^2}}{3a}} \leq t_o \quad \dots(1)$$

[0023] The expansion of the multi-channelled flat tube 3 with partitions 15 which in cross-section are bent into mountain shapes (V-shapes) with two sides 27 of the length α and meeting with an angle 2θ was investigated. As shown in FIG. 5(a), when the internal pressure is raised, the force that acts on the walls 21w of the outer tube 21 pulls the partitions 15 that are bent in mountain shapes outward, thereby causing the partitions 15 to deform so that the inclination angle (half angle) θ of each side 27 approaches 90° . This deformation changes the inclination of the partitions and is referred to as "angle deformation". The angle deformation is assumed to be deformation that ends or is ceased where a partition 15 becomes straightened state. The straighten or straightened state of this specification is the state that a corner (base) 26 where the partition 15 is connected to the wall 21w of the outer tube 21 and the peak point 25 where the two sides 27 that form the mountain shape meet become offset substantially by only the thickness t_i of the partition 15. This state is shown in FIG. 6.

[0024] As shown in FIG. 5(b), deformation that occurs thereafter is assumed to be deformation (referred to as "stretch deformation") caused by stretching that reduces the thickness of the partitions 15. Accordingly, depending on the applied internal pressure, the mechanism by which the partitions 15 deform changes. This means that by applying pressure in a range from a pressure where angle deformation ends to a pressure where stretch deformation commences, it is possible to stably cause the partitions 15 to deform until the partitions 15 become substantially straight.

[0025] FIG. 7 shows the result of measuring the relationship between the inner height of the tube (the inner diameter or inner dimension in the minor axis Y) H_i and the internal pressure (the applied pressure). The solid line A1 shown in FIG. 7 shows measured values for the case where the plate thickness t_i of the partitions 15 is set at 0.19mm and the dot-dash line A2 shows values produced by calculating the tangent (tan) from the measured values of the angle θ by which the partitions 15 are bent. As can be understood from the solid line A1, when the thickness t_i of the partitions 15 is 0.19mm, the tube height H_i suddenly increases from a point where the internal pressure exceeds 2MPa or thereabouts, showing that angle deformation is occurring for the partitions 15. When the internal pressure is around 7.2MPa, the increasing of amount of deformation in the partitions 15 starts to fall and when the internal pressure is around 7.5MPa, the partitions 15 substantially stop deforming. By applying a pressure of over 7.5MPa or so, the partitions 15 become the straightened state, and even if the pressure is increased further, deformation of the partitions 15 does not proceed. It is therefore supposed that angle deformation of the partitions 15 has ended.

[0026] By comparing the calculated values shown by the dot-dash line A2 in FIG. 7 and the measured values shown by the solid line A1, it can be seen that angle deformation of the tubes has substantially ended at the point " $\tan\theta = H_i / (2t_i)$ ". As described earlier, when the peak points 25 of the partitions 15 are positioned so as to be displaced from the base parts 26 by only the thickness t_i of the partitions 15, it is assumed that the partitions 15 have been the straightened state and angle deformation has ended. When judging from the measured values A1, angle deformation ends at an internal pressure of around 7 to 8MPa. Accordingly, if the internal pressure used to expand the tubes is set at around 7 to 8MPa or higher, it will be possible the partitions 15 become the straightened state.

[0027] As shown in FIG. 8, there are tolerances for dimensions such as the thickness t_i of the partitions 15. Due to such tolerances, the relationship between the amount of deformation (i.e., the height of the tube) H_i and the internal pressure P changes. If the target value of the height H_i during tube expansion is set at a position like H2 in FIG. 8 where angle deformation has not ended, it will be necessary to control the internal pressure P in the individual tubes so that the height H_i becomes the target value H2. This kind of tube expansion operation is not economical to carry out and since there is a fall in the accuracy of the dimensions after expansion, the manufacturing yield of a heat exchanger that uses multi-channeled flat tubes also falls. On the other hand, if the target value of the height H_i during tube expansion is set at a position like H3 in FIG. 8 where angle deformation has ended, it will be possible to set the internal pressure during tube expansion at a value such as P_3 in FIG. 8, which can be the pressure at which angle deformation ends or an even higher pressure. This means that regardless of any differences between individual tubes, it will be possible to expand the tubes to the same height H_i by expanding the tubes with the same pressure. Since the accuracy of the dimensions of the tubes 3 after expansion is stabilized, the yield and quality of the heat exchanger 1 that uses the multi-channeled flat tubes 3 are improved.

[0028] In this way, by expanding the multi-channeled flat tubes 3 until the partitions 15 are the straightened state, that is, until the target value H3 shown in FIG. 8 is reached, it is possible to expand the multi-channeled flat tubes 3 stably. The pressure required to expand the tubes in this way is the pressure P_3 shown in FIG. 8, and the thickness t_o of the outer walls 21w of the outer tubes 21 is determined so that hardly any deformation is observed in the tube outer surface at such pressure P_3 .

[0029] The force (internal pressure) required for angle deformation of the partitions 15 can be calculated from the force applied when the partitions 15 become the straightened state as shown in FIG. 6. Having no intentional deformation of at least the outer walls 21w of the outer tubes 21 when such internal pressure is applied is one condition for the present invention. In FIG. 6, when the length of one side of the partitions 15 is expressed as length α , the inclination (bent angle) as angle θ , the face-to-face distance between adjacent partitions 15 along the inner surfaces of the outer walls 21w of the flat outer tubes 21 (i.e., the distance between surfaces of facing partitions 15) as L_i , and the height of the multi-channeled flat tubes 3 (i.e., the inner diameter or inner dimension in the minor axis direction of the flat outer tubes 21) as H_i , the stress σ_o produced in the outer walls 21w when the internal pressure P acts on the outer walls 21w is as follows. First, since the outer walls 21w can be regarded as fixed beams (beams whose both ends are fixed respectively) subjected to a uniformly distributed load of the pressure P along the inter-partition distance L_i , the maximum bending moment M_{max} and the section modulus Z are as shown by Equations (4) and (5). Accordingly, the maximum stress σ_o applied to the outer walls 21w is shown by Equation (6).

Equation 4

$$M_{max} = \frac{P \cdot L_i^2}{12} \dots (4)$$

Equation 5

$$Z = \frac{t_o^2}{6} \dots (5)$$

Equation 6

$$\sigma_o = \frac{M_{max}}{Z} = \frac{P \cdot L_i^2}{12} \times \frac{6}{t_o^2} = \frac{P \cdot L_i^2}{2t_o^2} \dots (6)$$

[0030] A partition 15 is pulled upward and downward by the forces that act at the bases 26. The bases 26 are subjected to a force (load) W (where W =applied pressure $P \times$ pressure-receiving surface length L_i) due to the internal pressure P . The partition 15 is thought to deform due to the bending moment acting on the bases 26 and the peak point 25 where

the center of the partition and the two sides 27 are joined. The partition 15 can be modeled as a fixed beam (beam whose both ends are fixed) of an effective length 2α and a thickness t_i that receives a concentrated load W' at the center 25 thereof. If the force W is constant, the concentrated load W' that acts on the partition 15 will be minimized when $\tan \theta$ is maximized, and therefore calculations can proceed for the conditions where angle deformation occurs for a minimum concentrated load W' . The condition that the $\tan \theta$ is maximized indicates that angle deformation has ended for the partition 15 and the partition 15 has been the straightened state, which means that the inclination θ can be expressed by Equation (7). Accordingly, the concentrated load W' can be found as shown in Equation (8).

Equation 7

$$\tan \theta = \frac{H_i/2}{t_i} = \frac{H_i}{2t_i} \dots (7)$$

Equation 8

$$W' = \frac{W}{\tan \theta} = \frac{P \cdot L_i}{\frac{H_i}{2t_i}} = \frac{2t_i \cdot P \cdot L_i}{H_i} \dots (8)$$

[0031] The maximum bending moment $M_{\max}$ during angle deformation of the partitions 15 is as shown in Equation (9). By using the section modulus Z in Equation (10), the maximum stress σ_i occurring in the partitions 15 is as shown in Equation (11). Note that since modeling is carried out based on the cross-sectional form of a multi-channelled flat tube, stress is calculated in one dimension.

Equation 9

$$M_{\max} = \frac{W' \cdot 2a}{8} = \frac{2t_i \cdot P \cdot L_i \cdot 2\sqrt{(H_i/2)^2 + t_i^2}}{8H_i} = \frac{t_i \cdot P \cdot L_i \sqrt{(H_i/2)^2 + t_i^2}}{2H_i} \dots (9)$$

Equation 10

$$Z = \frac{t_i^2}{6} \dots (10)$$

Equation 11

$$\sigma_i = \frac{M_{\max}}{Z} = \frac{t_i \cdot P \cdot L_i \sqrt{(H_i/2)^2 + t_i^2}}{2H_i} \times \frac{6}{t_i^2} = \frac{3P \cdot L_i \sqrt{(H_i/2)^2 + t_i^2}}{H_i \cdot t_i} \dots (11)$$

[0032] To expand the tubes according to the conditions described above, the outer walls 21w should not deform in a range of pressure where angle deformation occurs for the partitions 15. Accordingly, when the minimum pressure $P_{\min}$ for expanding the tubes is applied to the multi-channelled flat tubes 3, the threshold stress σ_{lim} of the material that

constructs the outer walls 21w and the partitions 15, for example, a metal material including aluminum and copper, the maximum stress σ_i when angle deformation occurs for the partitions 15, and the maximum stress σ_o applied to the outer walls 21w should satisfy Equation (12) below.

Equation 12

$$\sigma_o \leq \sigma_{lim} \leq \sigma_i \quad \dots (12)$$

[0033] From Equation (12), it is possible to reach Condition (1) above. Note that the length α of one side 27 of a partition 15 is expressed as shown in Equation (13) below.

Equation 13

$$a = \sqrt{(H_i/2)^2 + t_i^2} \quad \dots (13)$$

[0034] One merit of multi-channeled flat tubes is that the strength of the flat tubes is increased by the partitions disposed inside the tubes, and therefore the outer walls 21w, or in other words, the outer tubes 21 can be made thinner. Here, suppose the case of a double-channeled flat tube with two channels 14 that is the minimum configuration of a multi-channeled flat tube. When the internal pressure P is applied, the maximum stress σ_o produced in the outer walls 21w is as shown by Equation (6) given earlier. For a flat tube with the same internal cross-sectional area as such double-channeled flat tube, that is, a single flat tube with the distance $2L_i$ between walls and a tube inner dimension (i.e., height) of H_i , to achieve the same strength as the double-channeled flat tube, it would be necessary to double the thickness t_o of the outer walls 21 w. This means that if the thickness of the outer walls 21w is more than double the minimum value calculated using Equation (1), one of the merits of multi-channeled flat tubes will be lost. Accordingly, the thickness t_o of the outer walls 21w should preferably satisfy Condition (2).

Equation 2

$$2\sqrt{\frac{L_i \cdot t_i \cdot \sqrt{a^2 - t_i^2}}{3a}} \geq t_o \quad \dots (2)$$

[0035] In FIG. 8, if the pressure P is increased further, stretch deformation occurs for the partitions 15, so that the partitions 15 continue to extend while becoming thinner. In this case, it is difficult to know when the partitions 15 will rupture or break. For this reason, it is not preferable to expand the multi-channeled flat tubes 3 using a pressure P that causes stretch deformation to commence. Also, regarding the pressure used during expanding, it is not necessary for the outer walls 21w of the outer tubes 21 to withstand a pressure P thereby the stretch deformation commences without deforming, since such pressure is at or above the withstand pressure of the multi-channeled flat tubes for service. In addition, in view of cost and heat exchanging efficiency, the thickness t_o of the flat outer tubes 21 should preferably be thin. Accordingly, the thickness t_o of the outer tubes 21 can be such that the flat outer tubes 21 deform at a pressure that causes stretch deformation of the partitions 15. In addition, if the outer walls 21w deform when a pressure P that causes stretch deformation of the partitions 15 is applied, it will be clear that excessive pressure is being applied from the external appearance of the multi-channeled flat tubes 3, and therefore such appearance can be used as one judgment made to confirm the quality of the multi-channeled flat tubes 3 and of the heat exchanger 1 that uses such multi-channeled flat tubes 3.

[0036] When stretch deformation occurs for the partitions 15, the tensile stress σ_s that acts on the partitions 15 is as shown in Equation (14).

Equation 14

$$\sigma_s = \frac{P \cdot Li}{ti} \cdot \dots (14)$$

[0037] It is thought that the outer walls 21w should deform before stretch deformation occurs for the partitions 15. Accordingly, when the maximum pressure **Pmax** for expanding the tubes is applied to the multi-channeled flat tubes 3, the threshold stress **σlim** of the material of the multi-channeled flat tubes 3, the stress **σs** when stretch deformation occurs for the partitions 15, and the maximum stress **σo** applied to the outer walls 21w should satisfy Equation (15) below.

Equation 15

$$\sigma_s \leq \sigma_{lim} \leq \sigma_o \cdot \dots (15)$$

[0038] From Equation (15), it is possible to reach Condition (3), and the thickness **to** of the outer walls 21w should more preferably satisfy this condition.

Equation 3

$$\sqrt{\frac{Li \cdot ti}{2}} \geq to \dots (3)$$

[0039] FIG. 9 shows the thickness **to** of the outer walls 21w of the multi-channeled flat tubes 3 relative to the inter-partition distance **Li** and the partition wall thickness **ti** when the target value of the inner dimension **Hi** during tube expansion is 1.5mm. The plane **Cu** shown in FIG. 9 shows the upper limit of the thickness **to** according to Condition (3), and the plane **C1** shows the lower limit of the thickness **to** according to Condition (1). If the multi-channeled flat tubes 3 have outer tubes 21 with a thickness **to** in this range, it is possible to set a suitable pressure **P3**, as shown in FIG. 8, for expanding the tubes and therefore the tubes can be expanded with a favorable yield (lower defect rate). In addition, it is possible to prevent deformation of the outer walls 21w during expansion of the tubes, and therefore it is possible to achieve a high yield when manufacturing the heat exchanger 1 where the multi-channeled flat tubes 3 have a stabilized outer form and achieve a sufficient contact surface area with the fins 2, resulting in high heat exchanging efficiency. A specific example of the pressure **P3** which is suited to expanding the tubes until the inner dimension **Hi** reaches the desired target value within a range where angle deformation occurs for the partitions 15 without stretch deformation occurring for the partitions 15 can be set based on the threshold stress **σlim** of the material that constructs the multi-channeled flat tubes 3. By referring to Equations (12) and (15), it can be understood that the pressure **P3** for expanding the tubes should preferably be set in the range given below.

Equation 16

$$\frac{2 \cdot \sqrt{a^2 - ti^2}}{3Li \cdot a} \sigma_{lim} \leq P3 \leq \frac{ti}{Li} \sigma_{lim} \dots (16)$$

[0040] Note that as described above, although a procedure for manufacturing the heat exchanger 1 that has plate-like fins 2 has been described, the form of the fins is not limited to a plate-like form and wave-like corrugated fins may be used. In a heat exchanger that uses corrugated fins, only the parts of the multi-channeled flat tubes that are attached to the headers need to be expanded and it is fundamentally unnecessary to expand the parts of the multi-channeled flat

tubes that are joined to the fins. However, it is possible to expand the multi-channeled flat tubes after the fins have been joined to increase the contact surface area. When the insides of the multi-channeled flat tubes are partitioned into narrow channels by a plurality of partitions, since the individual channels have small cross-sectional areas, a method that extends the partitions by increasing the internal pressure by introducing a fluid into the multi-channeled flat tubes is more suitable than a method that expands the tubes by inserting tube expanders. However, by using multi-channeled flat tubes that satisfy Condition (1) given earlier, regardless of whether a method that raises the internal pressure (sometimes referred to as "pressurized tube expansion") or an expansion method that uses tube expanders is used, it will be possible to prevent the outer walls of the outer tubes, from deforming due to the internal pressure caused by the fluid or tube expanders, which would result in the outer surfaces of the outer tubes becoming wavy or undulating, before the partitions have extended to reach a desired size. That is, by using pressurized tube expansion or the like, when the multi-channeled flat tubes are expanded by internal pressure, it is possible to extend the partitions while suppressing deformation of the tube outer walls, and therefore the outer form of the tubes can be controlled until the multi-channeled flat tubes reach the desired size. By preventing the tube outer walls from deforming into an unintended shape, it is possible to achieve a sufficient contact surface area between the tube outer surfaces and the fins, thereby improving the heat transfer performance. Accordingly, it is possible to provide a heat exchanger that has high heat exchanging efficiency and high reliability.

Claims

1. A multi-channeled flat tube comprising:

a flat outer tube; and

a plurality of partitions that divide an inside of the outer tube into a plurality of channels,

wherein each of the plurality of partitions has a mountain-shaped cross-sectional form composed of two sides, each of the two sides has a thickness t_i and a length a , the plurality of partitions are disposed so that a face-to-face distance between adjacent partitions of the plurality of partitions along inner surfaces of the outer tube is L_i , and a thickness t_o of the outer tube satisfies a condition below

Equation 1

$$\sqrt{\frac{L_i \cdot t_i \cdot \sqrt{a^2 - t_i^2}}{3a}} \leq t_o .$$

2. The multi-channeled flat tube according to claim 1, wherein the thickness t_o of the outer tube also satisfies a condition below

Equation 2

$$2\sqrt{\frac{L_i \cdot t_i \cdot \sqrt{a^2 - t_i^2}}{3a}} \geq t_o .$$

3. The multi-channeled flat tube according to claim 1, wherein the thickness t_o of the outer tube also satisfies a condition below

Equation 3

5

$$\sqrt{\frac{Li \cdot ti}{2}} \geq to.$$

10

4. A heat exchanger comprising:

a plurality of multi-channeled flat tubes according to claim 1; and
a plurality of fins that are attached to the plurality of multi-channeled flat tubes and the plurality of multi-channeled flat tubes passing through the plurality of fins.

15

20

25

30

35

40

45

50

55

Fig. 1

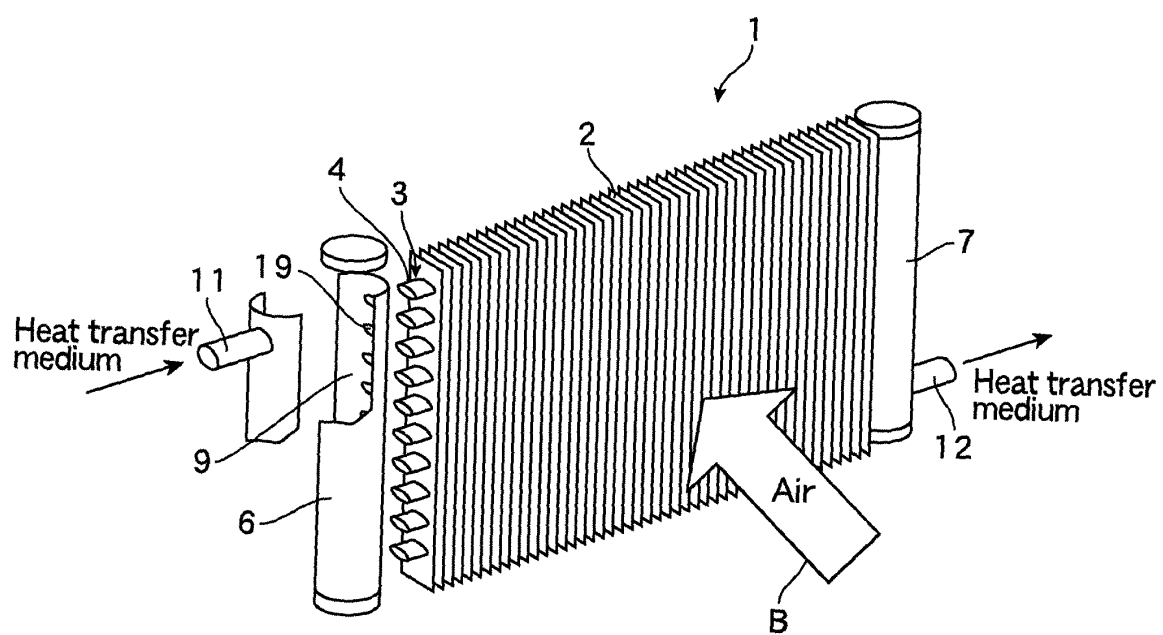


Fig. 2

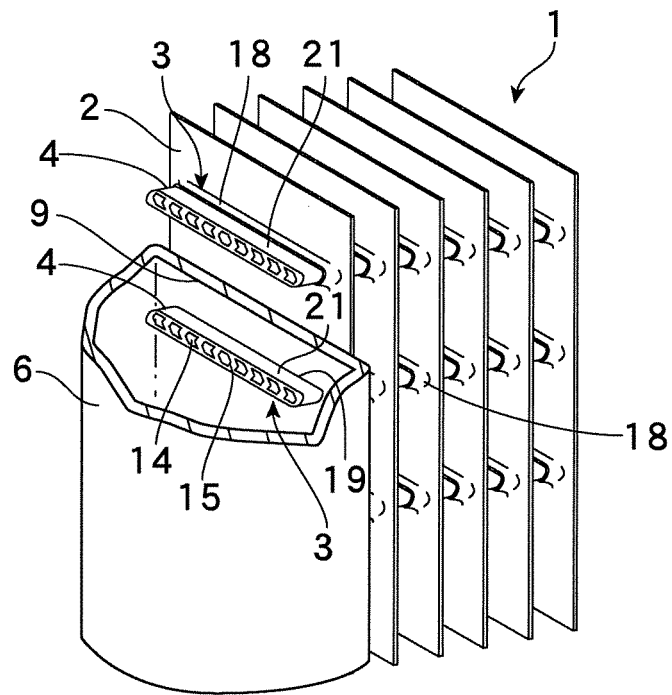


Fig. 3

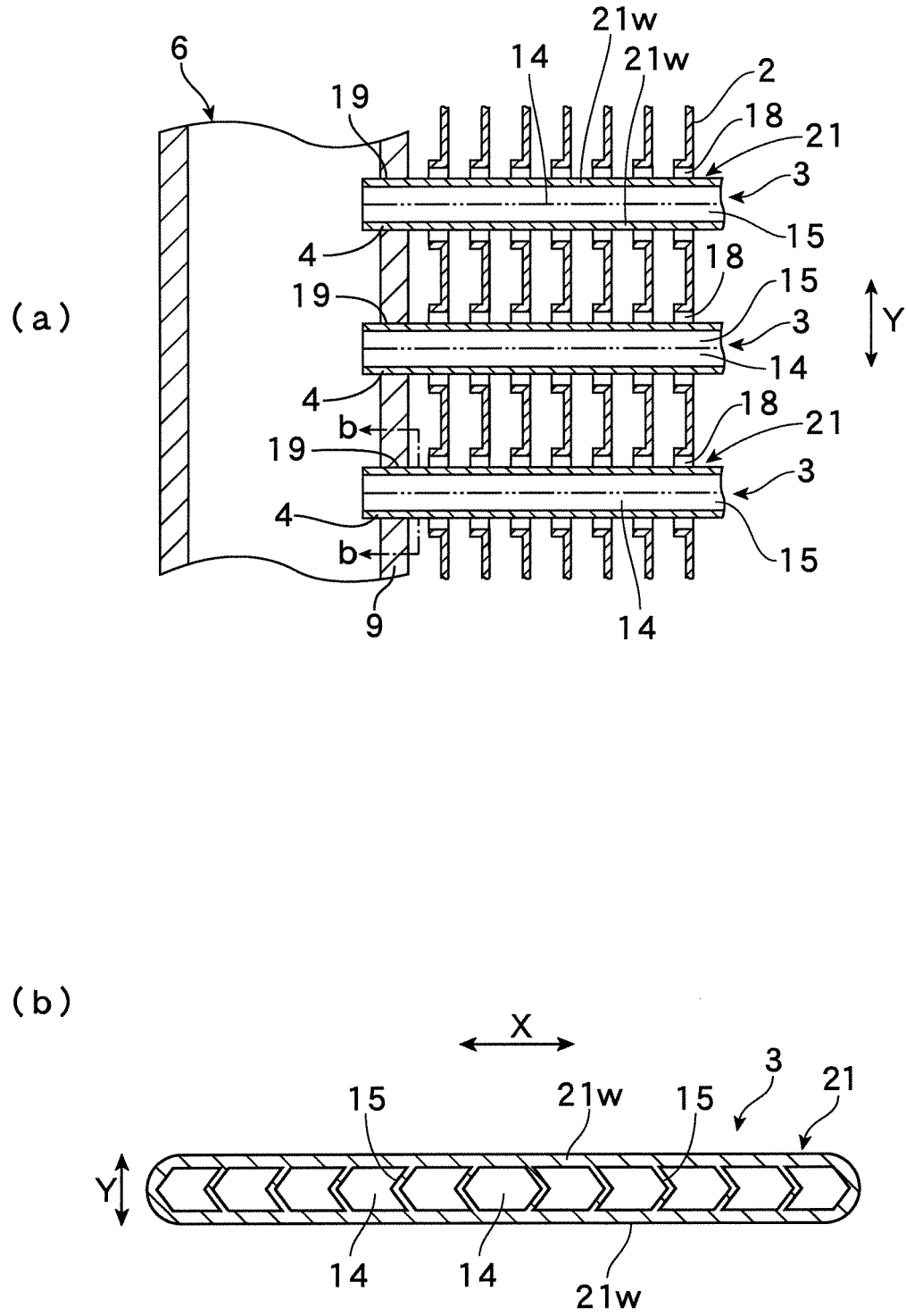


Fig. 4

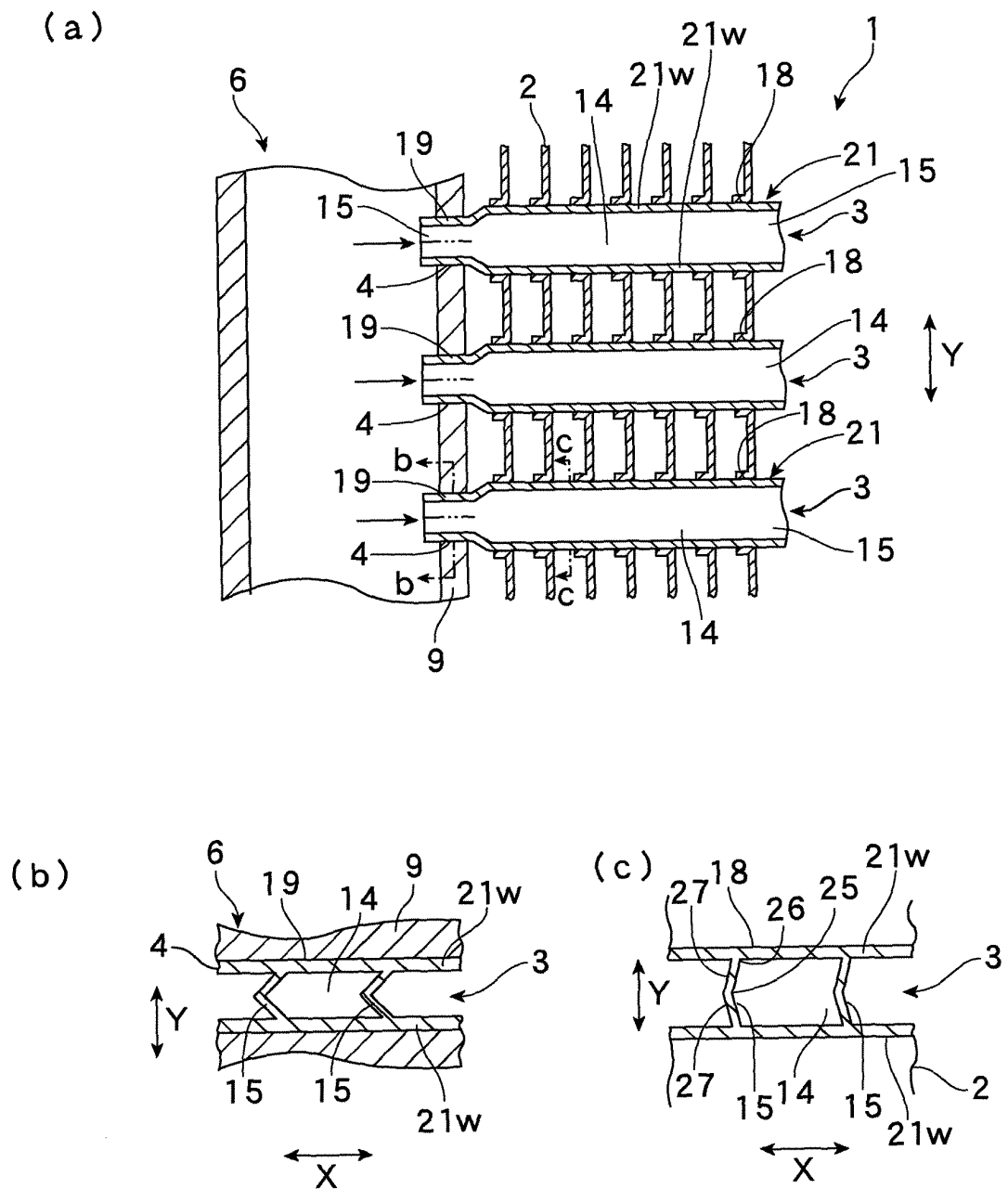


Fig. 5

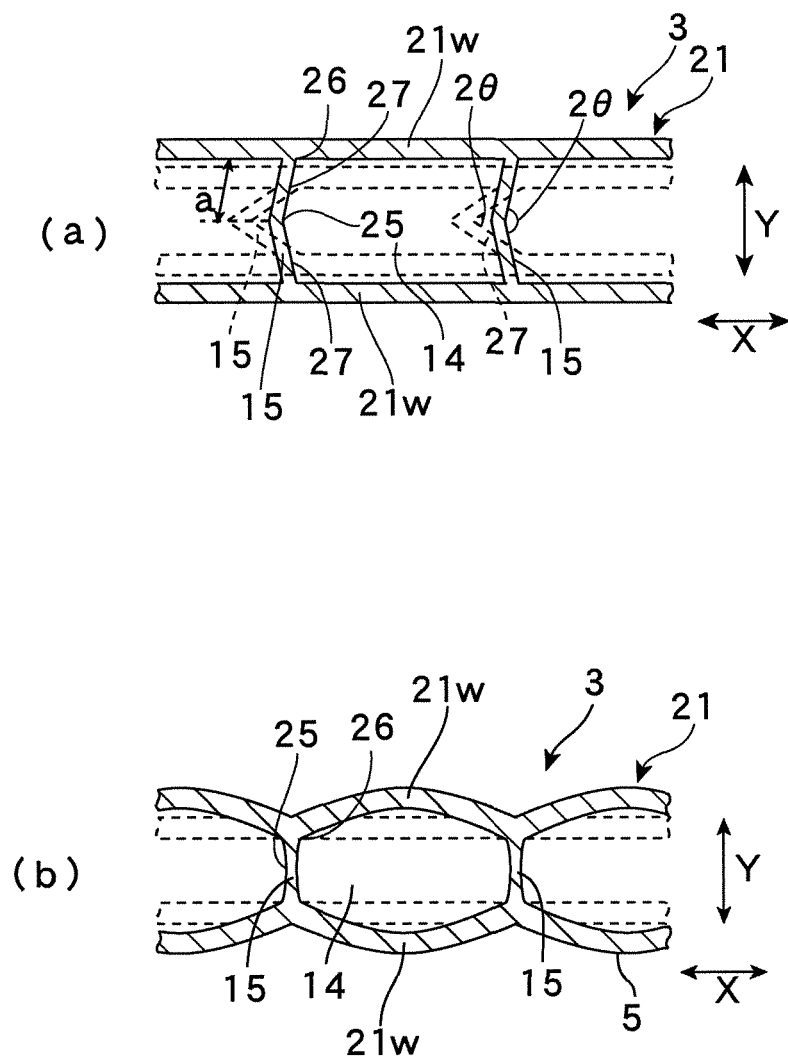


Fig. 6

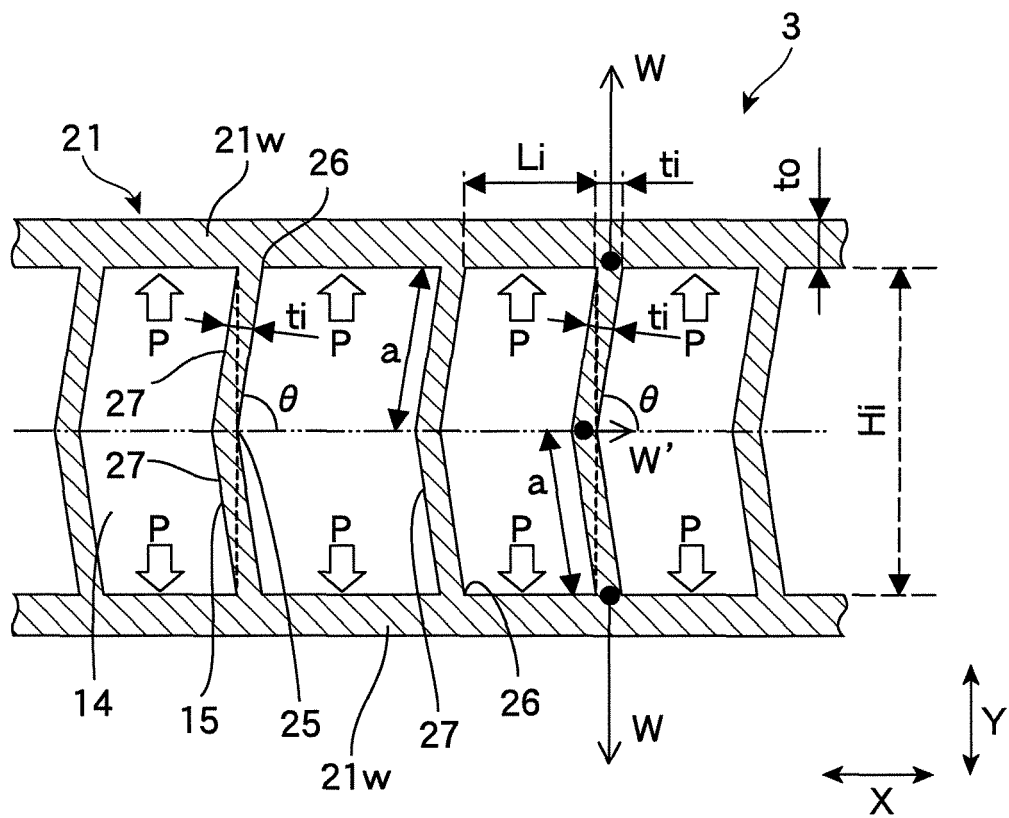


Fig. 7

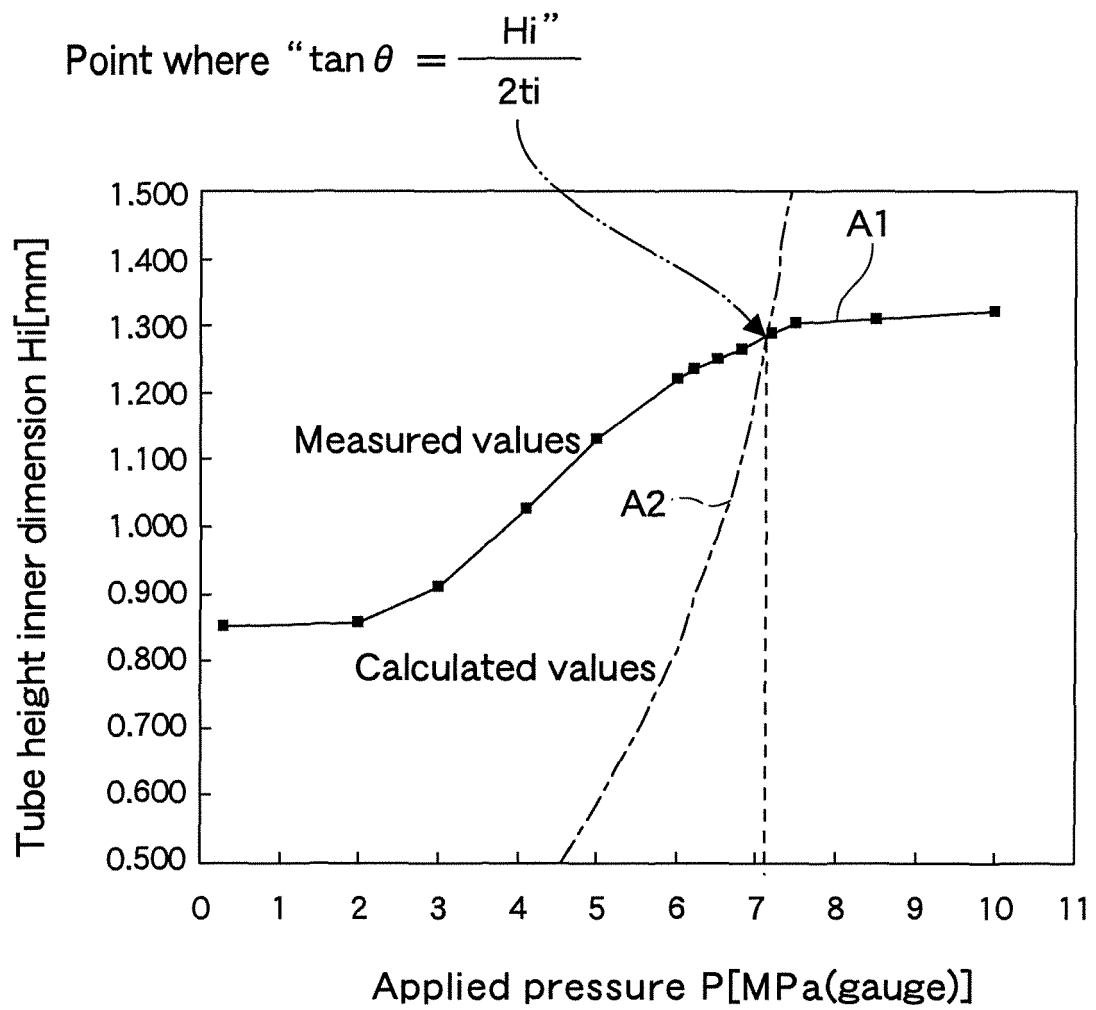


Fig. 8

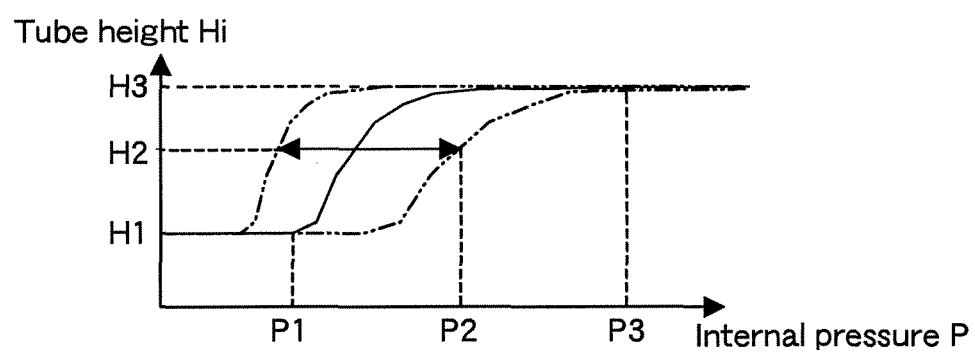
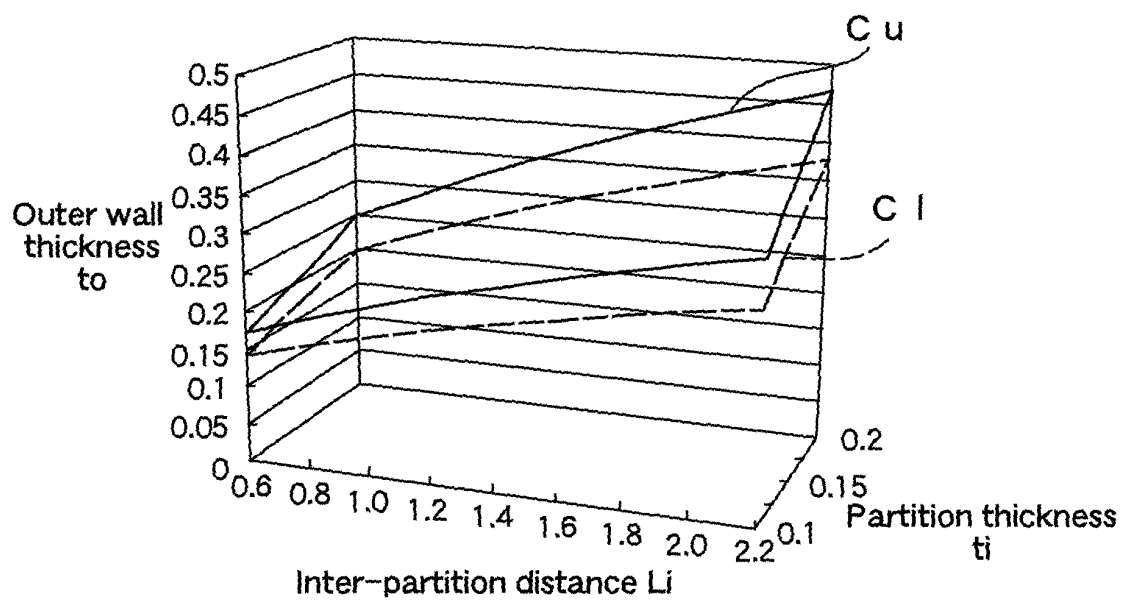


Fig. 9



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2005/015940

A. CLASSIFICATION OF SUBJECT MATTER

F28F1/02 (2006.01), **F28D1/053** (2006.01), **F28F1/32** (2006.01)

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)

F28F1/02 (2006.01), **F28D1/053** (2006.01), **F28F1/32** (2006.01)

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	1996-2005
Kokai Jitsuyo Shinan Koho	1971-2005	Toroku Jitsuyo Shinan Koho	1994-2005

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.
A	JP 2003-148889 A (GAC Corp.), 21 May, 2003 (21.05.03), & US 2005/61494 A & EP 1452819 A1 & WO 03/40642 A1 & CN 1585885 A	1-4
A	JP 61-268985 A (Matsushita Refrigeration Co.), 28 November, 1986 (28.11.86), (Family: none)	1-4
A	JP 1-127175 A (Hitachi, Ltd.), 19 May, 1989 (19.05.89), (Family: none)	1-4

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

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"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)

"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

"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

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search
29 November, 2005 (29.11.05)Date of mailing of the international search report
13 December, 2005 (13.12.05)Name and mailing address of the ISA/
Japanese Patent Office

Authorized officer

Facsimile No.

Telephone No.

Form PCT/ISA/210 (second sheet) (April 2005)

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- JP 62019691 A [0004]