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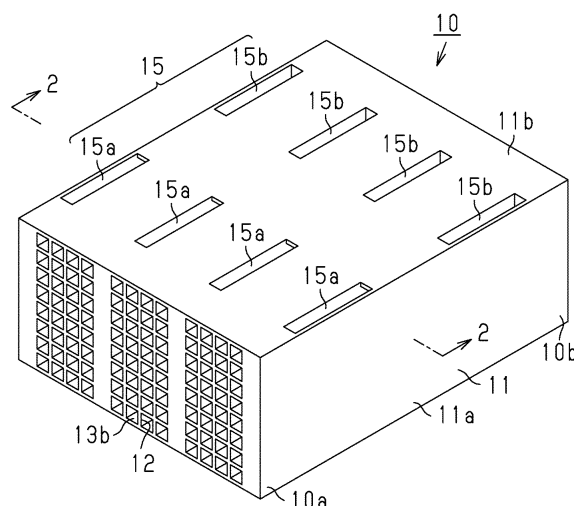
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(54) **HEAT EXCHANGER**

(57) A heat exchanger 10 that comprises a tubular peripheral wall 11 and a partitioning wall 12 that divides the inside of the peripheral wall 11 into a plurality of heat medium passage cells 13a and a plurality of gas passage cells 13b that extend in the axial direction of the peripheral

wall 11. Heat exchange occurs between the heat medium that flows through the heat medium passage cells 13a and the gas that flows through the gas passage cells 13b. The number ratio between the heat medium passage cells 13a and the gas passage cells 13b is 1:3-1:6.

Fig.1



Description

TECHNICAL FIELD

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

BACKGROUND ART

[0002] As shown in Fig. 14, a heat exchanger 40 of Patent Document 1 includes an outer wall 41 and partition walls 44. The outer wall 41 has the form of a rectangular tube. The partition walls 44 partition the inner side of the outer wall 41 into a plurality of first cells 42 and a plurality of second cells 43 extending in an axial direction of the outer wall 41. In a cross section orthogonal to the axial direction of the outer wall 41, the first cells 42 and the second cells 43 are arranged in lines in a vertical direction. Specifically, from the left side of the plane of Fig. 14, the first cells 42 are located in the first, third, fifth, and seventh lines, and the second cells 43 are located in the second, fourth, sixth, and eighth lines. In the heat exchanger 40, heat is exchanged between a first fluid flowing through the first cells 42 and a second fluid flowing through the second cells 43.

[0003] The heat exchanger 40 of Patent Document 1 is set so that each second cell 43 has a cross-sectional flow area that is larger than that of each first cell 42. When heat is exchanged between fluids having different thermal capacities, the second fluid having a smaller thermal capacity flows through the second cells 43 having a larger cross-sectional flow area to increase the amount of the second fluid in the heat exchanger 40. This matches the thermal capacity of the first fluid as a whole with the thermal capacity of the second fluid as a whole in the heat exchanger 40 and increases the heat exchange efficiency.

PRIOR ART LITERATURE

PATENT LITERATURE

[0004] Patent Document 1: Japanese Laid-Open Patent Publication No. 2015-140960

SUMMARY OF THE INVENTION

PROBLEMS THAT THE INVENTION IS TO SOLVE

[0005] A heat exchanger such as that shown in Fig. 14 may be used to exchange heat between a gas, such as exhaust gas, and a liquid heat medium, such as a coolant. In this case, the heat of the gas is transferred through the partition walls of the heat exchanger to the liquid heat medium. However, it is difficult to increase the heat exchange efficiency of the heat exchanger because the heat of the gas transferred to the partition walls is limited. Accordingly, one object of the present invention is to provide a heat exchanger that increases the heat exchange efficiency.

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MEANS FOR SOLVING THE PROBLEMS

[0006] A heat exchanger in accordance with the present invention that solves the above problem includes a tubular outer wall and partition walls that partition an inner side of the outer wall into heat medium passage cells and gas passage cells extending in an axial direction of the outer wall. The heat exchanger exchanges heat between a liquid heat medium flowing through the heat medium passage cells and a gas flowing through the gas passage cells. The ratio of the number of the heat medium passage cells to the number of the gas passage cells is 1:3 to 1:6.

[0007] With this structure, the number of gas passage cells is three times or greater than the number of heat medium passage cells thereby increasing the total cross-sectional flow area of the gas passage cells and decreasing the velocity of the gas flowing through the gas passage cells. This increases the amount of time of contact between the gas and the partition walls and also increases the area of contact between the gas and the partition walls. Thus, the heat of the gas is readily transferred to the partition walls. Also, the number of the gas passage cells are less than or equal to six times of the number of the heat medium passage cells. This allows the liquid heat medium flowing through the heat medium passage cells to completely cool the partition walls. When the partition walls are cooled completely, the heat of the gas will be quickly transferred. As a result, the heat exchange efficiency of the heat exchanger is increased.

[0008] With the heat exchanger in accordance with the present invention, it is preferred that the outer wall has the form of a rectangular tube that includes two opposing first side walls and two opposing second side walls. Further, it is preferred that the heat medium passage cells and the gas passage cells are arranged in heat medium passage cell lines and gas passage cell lines that are parallel to the first side walls in a cross section orthogonal to the axial direction of the outer wall. Preferably, three to six of the gas passage cell lines are arranged between two adjacent ones of the heat medium passage cell lines in a direction extending along the second side walls. With this structure, the concentrated arrangement of the heat medium passage cells and the arrangement of most of the heat medium passage cells in a certain range of the gas passage cells facilitate the partition walls to be completely cooled and reduces pressure loss.

[0009] With the heat exchanger in accordance with the present invention, it is preferred that the outer wall has one side including an inlet and an outlet for a heat medium that are connected with the heat medium passage cells. With this structure, the arrangement of the inlet and the outlet for the heat medium in one side of the heat exchanger decreases the total volume when connecting, for example, pipes through which the heat medium flows.

[0010] With the heat exchanger of the present invention, it is preferred that the heat medium passage cells each have the same cross-sectional shape and the gas passage cells each have the same cross-sectional shape in a cross section orthogonal to the axial direction of the outer wall. This structure eliminates differences in the heat exchange efficiency between the gas passage cells and differences in the heat exchange efficiency between the heat medium passage cells, which would have otherwise been caused by different cross-sectional shapes. This also reduces pressure loss in the gas passage cells.

[0011] With the heat exchanger of the present invention, it is preferred that each of the heat medium passage cells has a cross-sectional shape that is larger in size than that of each of the gas passage cells in a cross section orthogonal to the axial direction of the outer wall. The heat medium flowing through the heat medium passage cells is a liquid. Thus, the heat medium has a larger passage resistance than the gas when flowing through the cells. This structure facilitates the flow of the heat medium having a higher flow resistance.

[0012] With the heat exchanger of the present invention, it is preferred that the partition walls include silicon carbide as a main component. The silicon carbide has a relatively high thermal conductivity among ceramic materials. Thus, this structure increases the thermal conductivity of the partition walls and increases the heat exchange efficiency of the heat exchanger.

EFFECT OF THE INVENTION

[0013] The present invention succeeds in increasing heat exchange efficiency.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014]

Fig. 1 is a perspective view of a heat exchanger.

Fig. 2 is a cross-sectional view taken along line 2-2 in Fig. 1.

Fig. 3 is a cross-sectional view taken along line 3-3 in Fig. 2.

Fig. 4 is a cross-sectional view taken along line 4-4 in Fig. 2.

Fig. 5 is a diagram illustrating a molding step.

Fig. 6 is a diagram illustrating a processing step (a diagram illustrating a state in which a processing jig for a first process is stuck in a molded body).

Fig. 7 is a diagram illustrating the processing step (a diagram illustrating a state in which the processing jig for the first process is stuck in and then pulled out of the molded body).

Fig. 8 is a diagram illustrating the processing step (a diagram illustrating a second process).

Fig. 9 is a diagram illustrating a degreasing step.

Fig. 10 is a diagram illustrating an impregnation step.

Fig. 11 is a front view of a heat exchanger of a modified example.

ified example.

Fig. 12 is a schematic diagram showing a dimension measurement point in a simulation.

Fig. 13 is a temperature distribution chart obtained from the simulation.

Fig. 14 is a cross-sectional view of a prior art heat exchanger.

MODES FOR CARRYING OUT THE INVENTION

[0015] One embodiment of a heat exchanger will now be described.

[0016] As shown in Figs. 1 and 2, a heat exchanger 10 of the present embodiment includes an outer wall 11 and partition walls 12. The outer wall 11 has the form of a rectangular tube. The partition walls 12 partition the inner side of the outer wall 11 into a plurality of heat medium passage cells 13a and a plurality of gas passage cells 13b extending in an axial direction of the outer wall 11. The outer wall 11, which has the form of a rectangular tube, includes two opposing vertical side walls 11a (first side walls) and two opposing lateral side walls 11b (second side walls). The outer wall 11 is configured so that its cross section orthogonal to the axial direction is rectangular and laterally elongated.

[0017] As shown in Fig. 2, in a cross section orthogonal to the axial direction of the outer wall 11, the partition walls 12 form a grid-like cell structure and include partition walls 12 parallel to the vertical side walls 11a and partition walls 12 parallel to the lateral side walls 11b. The cell structure of the partition walls 12 is not particularly limited. For example, the cell structure may be configured so that the partition walls 12 have a thickness of 0.1 to 0.5 mm and a cell density of 15 to 93 cells per 1 cm² in a cross section orthogonal to the axial direction of the outer wall 11.

[0018] As shown in Fig. 3, the heat medium passage cells 13a, through which a heat medium flows, each include two ends that are sealed by a sealed portion 22. As shown in Fig. 4, each gas passage cell 13b, through which a gas subject to processing flows, includes two open ends. The heat medium is not particularly limited and a known liquid heat medium may be used. Examples of known heat medium include a coolant (long life coolant (LLC)) and an organic solvent, such as ethylene glycol. The gas subject to processing may be, for example, exhaust gas of an internal combustion engine.

[0019] As shown in Fig. 2, in a cross section orthogonal to the axial direction of the outer wall 11, each heat medium passage cell 13a has the same cross-sectional shape as the gas passage cells 13b.

[0020] As shown in Fig. 2, the heat exchanger 10 includes a plurality of heat medium passage cell lines 14a and a plurality of gas passage cell lines 14b. The heat medium passage cell lines 14a include only the heat medium passage cells 13a arranged parallel to the vertical side walls 11a of the outer wall 11, and the gas passage cell lines 14b include only the gas passage cells 13b ar-

ranged parallel to the vertical side walls 11a.

[0021] The heat exchanger 10 is set so that the ratio of the number of the heat medium passage cells 13a to the number of the gas passage cells 13b is in a certain range. The ratio (heat medium passage cells 13a : gas passage cells 13b) is 1:3 to 1:6, and preferably, 1:4 to 1:5.

[0022] In the present embodiment, the ratio is adjusted by the arrangement of the heat medium passage cell lines 14a and the gas passage cell lines 14b. Specifically, in a direction extending along the lateral side walls 11b of the outer wall 11, a plurality of gas passage cell lines 14b are arranged between two adjacent heat medium passage cell lines 14a. This arrangement is repeated in the direction of the lateral side walls 11b of the outer wall 11 to form an arrangement pattern. When the number of the gas passage cell lines 14b arranged between two adjacent heat medium passage cell lines 14a is three to six, the ratio is 1:3 to 1:6. Preferably, the number of the gas passage cell lines 14b arranged between two adjacent heat medium passage cell lines 14a is four to five.

[0023] As shown in Figs. 1 and 3, in the heat exchanger 10, the heat medium passage cell lines 14a each include a connection portion 15 extending in the vertical direction. The connection portion 15 extends through the partition walls 12 between adjacent heat medium passage cells 13a in the vertical direction and connects the cells of heat medium passage cell lines 14a. The connection portion 15 has an end at one side in the vertical direction (upper side in Fig. 3) that opens in the outer walls 11 (lateral side wall 11b) and an end at the other side in the vertical direction (lower side in Fig. 3) reaching the heat medium passage cell 13a that is the farthest from the opening of the connection portion 15. In other words, each connection portion 15 opens in one side of the outer wall 11 and extends to the heat medium passage cell 13a that is the farthest from the opening of the connection portion 15. The connection portion 15 of the heat exchanger 10 includes a first connection portion 15a and a second connection portion 15b. The first connection portion 15a is arranged closer to a first end 10a, which is located at one side in the axial direction of the heat exchanger 10, and the second connection portion 15b is arranged closer to a second end 10b, which is located at the other side in the axial direction of the heat exchanger 10.

[0024] As shown in Fig. 3, a heat medium flow passage 16 is formed inside the heat exchanger 10 by the heat medium passage cells 13a, the first connection portion 15a, and the second connection portion 15b. The opening of the first connection portion 15a and the opening of the second connection portion 15b in the outer wall 11 of the heat exchanger function as an inlet or an outlet of the heat medium flow passage 16. Further, as shown in Fig. 4, a gas flow passage 17 is formed inside the heat exchanger 10 by each gas passage cell 13b, with its axial ends 10a and 10b functioning as an inlet or an outlet of the gas flow passage 17. The heat exchanger 10 exchanges heat through the partition walls 12 between the heat medium flowing through the heat medium flow pas-

sages 16 and the gas flowing through the gas flow passages 17.

[0025] The material of the outer wall 11, which has the form of a rectangular tube, and the partition walls 12 of the heat exchanger 10 is not particularly limited. The material of a known heat exchanger may be used. The material is, for example, a carbide, such as silicon carbide, tantalum carbide, and tungsten carbide, or a nitride, such as silicon nitride and boron nitride. Among these substances, a material including silicon carbide as a main component is preferred since it has a higher thermal conductivity than other ceramic materials and increases the heat exchange efficiency. Here, "main component" refers to a component that is greater than or equal to 50% by mass. An example of a material including silicon carbide as a main component is a material including silicon carbide particles and metal silicon.

[0026] A method for manufacturing the heat exchanger of the present embodiment will now be described with reference to Figs. 5 to 10. The heat exchanger is manufactured by sequentially performing a molding step, a processing step, a degreasing step, and an impregnation step as described below.

25 Molding Step

[0027] As a raw material for molding the heat exchanger, silicon carbide particles, an organic binder, and a dispersion medium are mixed to prepare a clay-like mixture. A molded body 20 shown in Fig. 5 is molded from the clay-like mixture. The molded body 20 includes the outer wall 11, which has the form of a rectangular tube, and the partition walls 12, which partition the inner side of the outer wall 11 into a plurality of cells 13 extending in the axial direction of the outer wall 11. The cells 13 in the molded body 20 each have two open ends. The molded body 20 can be molded, for example, by extrusion molding. A drying process is performed on the obtained molded body 20 to dry the molded body 20.

40 Processing Step

[0028] In the processing step, a first process and a second process are performed. The first process is performed to form first connection portions and second connection portions in the molded body. The second process is performed to seal the two ends in some of the cells of the molded body.

[0029] As shown in Fig. 6, in the first process, for example, the first connection portions 15a and the second connection portions 15b are formed by a heated processing tool 21 that contacts the molded body and removes parts of the outer wall 11 and the partition walls 12 of the molded body 20.

[0030] Specifically, as shown in Fig. 6, a blade having a contour that corresponds to the first connection portion 15a and the second connection portion 15b is prepared as the processing tool 21. The blade is formed from a

heat resistant metal (e.g., stainless steel) and has a thickness that is set so as not to exceed the width of the heat medium passage cell 13a. Subsequently, the blade is heated to a temperature at which the organic binder included in the molded body 20 is burned and removed. For example, when the organic binder is methyl cellulose, the blade is heated to 400°C or higher.

[0031] As shown in Fig. 7, the heated blade is stuck into the molded body 20 from an outer side and then pulled out to form the first connection portions 15a and the second connection portions 15b. In this case, when the heated blade contacts the molded body 20, the organic binder included in the molded body 20 is burned and removed at the contact portion. Thus, the insertion resistance of the molded body 20 against the blade is extremely small. This limits deformation and breakage around the portion where the blade is stuck. Further, the burned and removed organic binder reduces the amount of processing waste.

[0032] As shown in Fig. 8, in the second process, among the cells 13 of the molded body 20, two ends of each cell 13 defining one heat medium passage cell 13a are sealed with the clay-like mixture used in the molding step. This forms the sealed portions 22 that seal the two ends of the cell 13. Then, a drying process is performed on the molded body 20 to dry the sealed portions 22.

[0033] A processed molded body is obtained by performing the processing step including the first process and the second process. The order in which the first process and the second process are performed is not particularly limited. The first process may be performed after the second process.

Degreasing Step

[0034] In the degreasing step, the processed molded body is heated to burn and remove the organic binder included in the processed molded body. This removes the organic binder from the processed molded body and obtains a degreased body. As shown in Fig. 9, a degreased body 30, in which the organic binder is removed from the processed molded body in the degreasing step, has a frame portion arranged in a state in which silicon carbide particles are in contact with one another.

Impregnating Step

[0035] In the impregnation step, the inside of each wall forming the degreased body is impregnated with metal silicon. In the impregnation step, the degreased body is heated in a state contacting a cluster of metal silicon to a melting point of the metal silicon or higher (for example, 1450°C or higher). As shown in Fig. 10, molten metal silicon enters the voids between particles, which form the frame portion of the degreased body, through capillary action and impregnates the voids.

[0036] The heating process in the impregnation step may be performed successively with the heating process

of the degreasing step. For example, in a state contacting a cluster of metal silicon, the processed molded body may be heated at a temperature lower than the melting point of metal silicon to remove the organic binder and obtain the degreased body. Then, the heating temperature may be raised to the melting point of the metal silicon or higher to impregnate the degreased body with the molten metal silicon.

[0037] The heat exchanger is obtained by performing the impregnation step.

[0038] In the present embodiment, special temperature management is performed in the steps from the degreasing step. Specifically, the steps from the degreasing step are performed at a lower temperature than a sintering temperature of the silicon carbide included in the mixture used in the molding step so that the processed molded body and the degreased body are not exposed to a temperature higher than or equal to the sintering temperature. Therefore, in the degreasing step, heating is performed at a temperature that is higher than or equal to a temperature that burns and removes the organic binder and lower than the sintering temperature. In the same manner, in the impregnation step, heating is performed at a temperature higher than or equal to the melting point of metal silicon and lower than the sintering temperature.

[0039] The operation and advantages of the present embodiment will now be described.

(1) The ratio of the number of the heat medium passage cells to the gas passage cells of the heat exchanger is 1:3 to 1:6. The number of the gas passage cells is three times or greater than the number of the heat medium passage cells. Thus, a total cross-sectional flow area of the gas passage cells is increased, and the velocity of the gas flowing through the gas passage cells is decreased. This increases the amount of time of contact between the gas and the partition walls and the area of contact between the gas and the partition walls thereby allowing heat to be readily transferred from the gas to the partition walls. Also, the number of the gas passage cells is less than or equal to six times of the number of the heat medium passage cells. This allows the liquid heat medium flowing through the heat medium passage cells to completely cool the partition walls. When the partition walls are completely cooled, the heat of the gas will be quickly transferred. As a result, the heat exchange efficiency of the heat exchanger is increased.

(2) Three to six gas passage cell lines are arranged between two adjacent heat medium passage cell lines. The concentrated arrangement of the heat medium passage cells and the arrangement of most of the heat medium passage cells in a certain range of the gas passage cells facilitate the partition walls to be completely cooled. Further, pressure loss is reduced.

(3) The inlets and the outlets for the heat medium,

which are connected with the heat medium passage cells, are located in the same side of the outer wall. The arrangement of the inlets and the outlets of the heat medium on one side of the heat exchanger allows the total volume to be decreased when connecting, for example, pipes through which the heat medium flows.

(4) In a cross section orthogonal to the axial direction of the outer wall, the heat medium passage cells each have the same cross-sectional shape, and the gas passage cells each have the same cross-sectional shape. This eliminates differences in the heat exchange efficiency between the gas passage cells and differences in the heat exchange efficiency between the heat medium passage cells that would result from different cross-sectional shapes.

(5) The partition walls include silicon carbide as a main component. Among ceramic materials, silicon carbide has a relatively high thermal conductivity. Thus, the partition walls, which include silicon carbide as a main component, have high thermal conductivity. This increases the heat exchange efficiency of the heat exchanger.

(6) The heat exchanger of the present embodiment is manufactured by performing temperature management as described above. The frame portion is formed in a state in which the silicon carbide particles are in contact with one another, and the shape of the frame portion is held with the voids filled with the silicon carbide. In other words, the silicon carbide particles do not include connected portions (necks), which result from sintering. This prevents cracking of necks between the silicon carbide particles even when internal temperature differences cause distortion in the partition walls during use of the heat exchanger. This further prevents cracks from spreading through necks.

[0040] The present embodiment may be modified as described below. Also, the configuration of the above embodiment and following modifications may be combined.

- In the present embodiment, the cells are arranged in the vertical direction of the outer wall, which has the form of a rectangular tube. However, the cells do not have to be arranged in the vertical direction. The heat exchanger may be used sideways and the cells may be arranged in a lateral direction.
- The heat medium passage cell lines are not limited to a configuration that only includes the heat medium passage cells. The heat medium passage cell lines may be configured so that 80% or more of the cells are the heat medium passage cells. Further, the gas passage cell lines are not limited to a configuration that only includes the gas passage cells. The heat gas passage cell lines may be configured so that 80% or more of the cells are the gas passage cells. That is, 20% or less of the heat medium passage

cell lines may be the gas passage cells. Further, 20% or less of the heat medium passage cell lines may be the heat medium passage cells.

- The outer wall does not need to have the form of a rectangular tube. The outer wall may have the form of a round tube or a tube having an elliptic cross section. Also, the partition walls do not have to be grid-like in which the partition walls intersect each other at approximately 90°. The partition walls may be configured so that the cells have cross sections other than rectangular cross sections, such as rhombic or polygonal cross sections. For example, the partition walls may be configured to have hexagonal cross sections. When the outer wall does not form a rectangular tube or when the partition walls are not grid-like and the partition walls do not intersect each other at approximately 90°, the outer wall may form cells with the partition walls that are shaped differently from the other cells. For example, in a configuration in which the partition walls form cells having hexagonal cross sections, the outer wall may form cells with the partition walls that have pentagonal or rectangular cross sections.
- The heat medium passage cells may have different cross-sectional shapes. The gas passage cells may have different cross-sectional shapes.
- In the present embodiment, the outer wall and the partition walls are formed of a material including silicon carbide as a main component. Instead, only the partition walls may be formed of a material including silicon carbide as a main component. Alternatively, the outer wall and the partition walls may be formed of a material other than one including silicon carbide as a main component.
- The cross-sectional shapes of the heat medium passage cells and the gas passage cells may differ in size in a cross section orthogonal to the axial direction of the outer wall. For example, as shown in Fig. 11, the heat medium passage cell 13a may be configured to have a larger widthwise dimension than the gas passage cells 13b so that the cross-sectional shape of each heat medium passage cell is increased in size. The liquid heat medium flowing through the heat medium passage cells has a greater passage resistance than a gas when flowing through the cells. Thus, when the heat medium passage cells each have a larger cross-sectional shape than the gas passage cells, the heat medium flows more smoothly. For example, in the configuration shown in Fig. 11, the widthwise dimension of the heat medium passage cell may be 1.0 to 5.0 mm, and the widthwise dimension of the gas passage cell may be 0.9 to 2.5 mm. Alternatively, the heat medium passage cells may each have a smaller widthwise dimension than the gas passage cells.
- In a configuration in which three to six gas passage cell lines are arranged between two adjacent heat medium passage cell lines, the number of the gas

passage cell lines, which is three to six, does not have to be fixed. That is, the number of the gas passage cell lines may vary from three to six.

- As long as the ratio of the heat medium passage cells to the gas passage cells is 1:3 to 1:6, the arrangement of the heat medium passage cells and the gas passage cells is not limited to the configuration in which three to six gas passage cell lines are arranged between two adjacent heat medium passage cell lines. The ratio of the number of the heat medium passage cells to the gas passage cells being 1:3 to 1:6 means that, for example, in any group of four vertical cells $\times$ seven lateral cells, there is four to seven heat medium passage cells.

EXAMPLES

[0041] Specific examples of the above described embodiment will now be described.

Example 1

[0042] First, a mixture having the composition described below was prepared.

Particles of silicon carbide with average particle size of 15 μm (large particles): 52.5 parts by mass
 Particles of silicon carbide with average particle size of 0.5 μm (small particles): 23.6 parts by mass
 Methyl cellulose (organic binder): 5.4 parts by mass
 Glycerol (lubricant): 1.1 parts by mass
 Polyoxyalkylene compound (plasticizer): 3.2 parts by mass
 Water (dispersion medium): 11.5 parts by mass

[0043] With this mixture, a molded body was molded to have a honeycomb structure in which the height was 50 mm, the width was 100 mm, the length was 100 mm, the thickness of the outer wall was 0.3 mm, the thickness of the partition walls was 0.25 mm, and the cell width was 1.2 mm.

[0044] Next, a plate-like jig heated to 400°C was stuck into the outer wall of the molded body to form the first connection portions and the second connection portions. Then, predetermined cells were sealed with a clay-like mixture having the same composition as the above-described mixture to form the processed molded body in which four gas passage cell lines were arranged between two adjacent heat medium passage cell lines. In other words, in the processed molded body, the ratio of the number of the heat medium passage cells to the number of the gas passage cells was 1:4. Subsequently, the processed molded body was heated at 450°C for five hours to remove the organic binder and obtain the degreased body. Then, the degreased body was heated at 1550°C for seven hours in a vacuum in a state in which a 20 gram-metal silicon plate is placed on the degreased body to impregnate the degreased body with metal silicon and

obtain the heat exchanger of example 1.

Evaluation Tests

- [0045]** The heat exchanger of example 1 was evaluated for temperature distribution in the heat medium passage cells and the gas passage cells by a simulation. Further, heat exchangers of examples 2 to 4 were evaluated for temperature distribution under the same condition as example 1 except in that the number of the gas passage cell lines between two adjacent heat medium passage cell lines was set to three, five, and six, that is, the ratio of the numbers of the heat medium passage cells to the gas passage cells was set to 1:3, 1:5, and 1:6. Also, heat exchangers of comparative example 1 and 2 were evaluated for temperature distribution under the same condition as example 1 except in that the number of the gas passage cell lines between two adjacent heat medium passage cell lines was set to two and eight, that is, the ratio of the numbers of the heat medium passage cells to the gas passage cells was set to 1:2 and 1:8.

Simulation Condition

[0046] A simulation condition is described as below. Fig. 12 shows where measurements were taken with regard to the dimensions of a cell.

- Cell height T: 1.2 mm, cell width H: 1.2 mm, length of heat medium passage cell: 100 mm, length of gas passage cell: 100 mm
- Partition wall thickness W: 0.25 mm, thermal conductivity of partition wall: 190 W/m $\cdot$ K
- Temperature of heat medium: 40°C, flow rate of heat medium: 10 L/min
- Temperature of gas: 400°C, flow rate of gas: 10 g/sec
- Name of simulation software: Fluent (registered trademark, manufactured by ANSYS)

[0047] Fig. 13 shows the results of the simulation.

[0048] The left column in Fig. 13 shows the temperature distribution at a central portion in the axial direction of the heat exchanger (10 mm from axial end), and the right column in Fig. 13 shows the temperature distribution at an outlet side of the heat exchanger (90 mm from axial end). The temperature distribution in the cells is shown in different colors.

[0049] First, the temperature distribution of example 1 will be described. Halves of the heat medium passage cells (1/2 of each cell) were arranged at the left side, and two lines of the gas passage cells were located at the right side of the heat medium passage cells to set the ratio of the cells to 1:4. Then, the heat medium and the gas were distributed under a predetermined condition to measure the temperature distribution in the heat medium passage cells, the partition walls, and the gas passage cells.

[0050] As shown in Fig. 13, in examples 1 to 4, the heat medium passage cells and the partition walls were each less than or equal to 50°C. This indicates that the partition walls were completely cooled. At the central portion in the axial direction of the heat exchanger, the maximum temperature in the gas passage cells was lower than or equal to 120°C. At the outlet side of the heat exchanger, the maximum temperature in the gas passage cells was lower than or equal to 58°C. In particular, in examples 1 and 3, the region in which the temperature was close to 58°C was limited at the outlet side of the heat exchanger. Thus, it was confirmed that the gas in the gas passage cells was cooled in a preferred manner and the heat exchange efficiency was high.

[0051] In contrast, in comparative examples 1 and 2, at the central portion in the axial direction of the heat exchanger, the maximum temperature in the gas passage cells was higher than or equal to 120°C. At the outlet side of the heat exchanger, the maximum temperature in the gas passage cells was higher than or equal to 58°C. Also, in comparative example 2, a region in which the temperature of the partition walls was 50°C or higher was present at the central portion in the axial direction of the heat exchanger and thus the partition walls were not completely cooled. Thus, it was confirmed that the heat exchange efficiency was low.

DESCRIPTION OF THE REFERENCE NUMERALS

[0052] 10) heat exchanger, 11) outer wall, 12) partition wall, 13a) heat medium passage cell, 13b) gas passage cell.

Claims

1. A heat exchanger, comprising:

a tubular outer wall; and
partition walls that partition an inner side of the outer wall into heat medium passage cells and gas passage cells extending in an axial direction of the outer wall, wherein
the heat exchanger exchanges heat between a liquid heat medium flowing through the heat medium passage cells and a gas flowing through the gas passage cells, and
the ratio of the number of the heat medium passage cells to the number of the gas passage cells is 1:3 to 1:6.

2. The heat exchanger according to claim 1, wherein the outer wall has the form of a rectangular tube that includes two opposing first side walls and two opposing second side walls, the heat medium passage cells and the gas passage cells are arranged in heat medium passage cell lines and gas passage cell lines that are parallel to the

first side walls in a cross section orthogonal to the axial direction of the outer wall, and
three to six of the gas passage cell lines are arranged between two adjacent ones of the heat medium passage cell lines in a direction extending along the second side walls.

3. The heat exchanger according to claim 1 or 2, wherein the outer wall has one side including an inlet and an outlet for a heat medium that are connected with the heat medium passage cells.

4. The heat exchanger according to any one of claims 1 to 3, wherein the heat medium passage cells each have the same cross-sectional shape and the gas passage cells each have the same cross-sectional shape in a cross section orthogonal to the axial direction of the outer wall.

5. The heat exchanger according to any one of claims 1 to 4, wherein each of the heat medium passage cells has a cross-sectional shape that is larger in size than that of each of the gas passage cells in a cross section orthogonal to the axial direction of the outer wall.

6. The heat exchanger according to any one of claims 1 to 5, wherein the partition walls include silicon carbide as a main component.

Fig.1

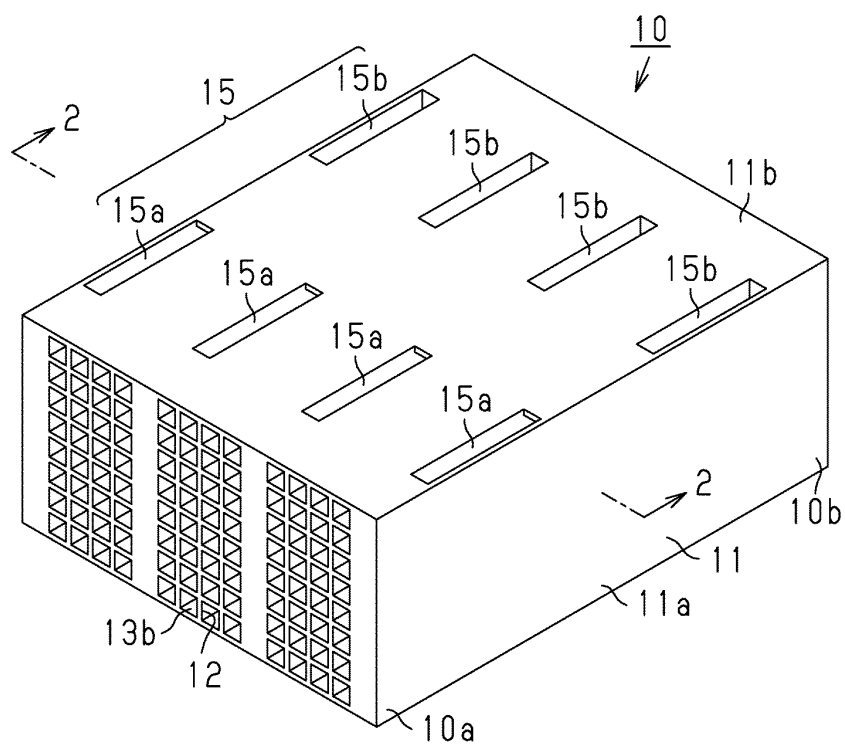


Fig.2

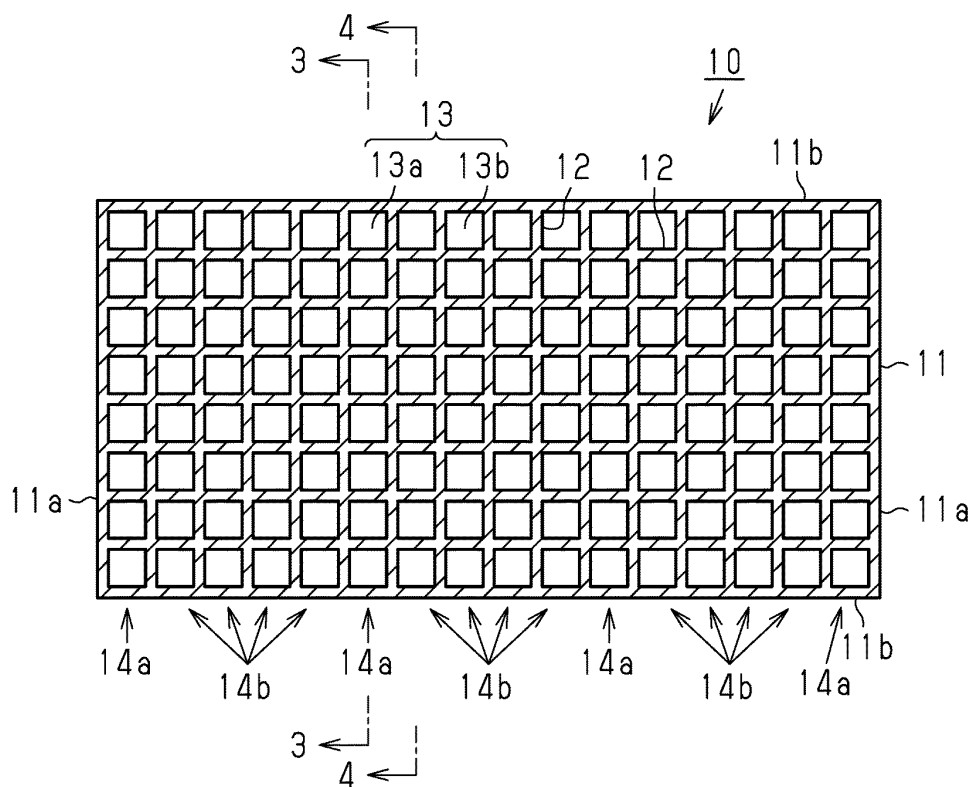


Fig.3

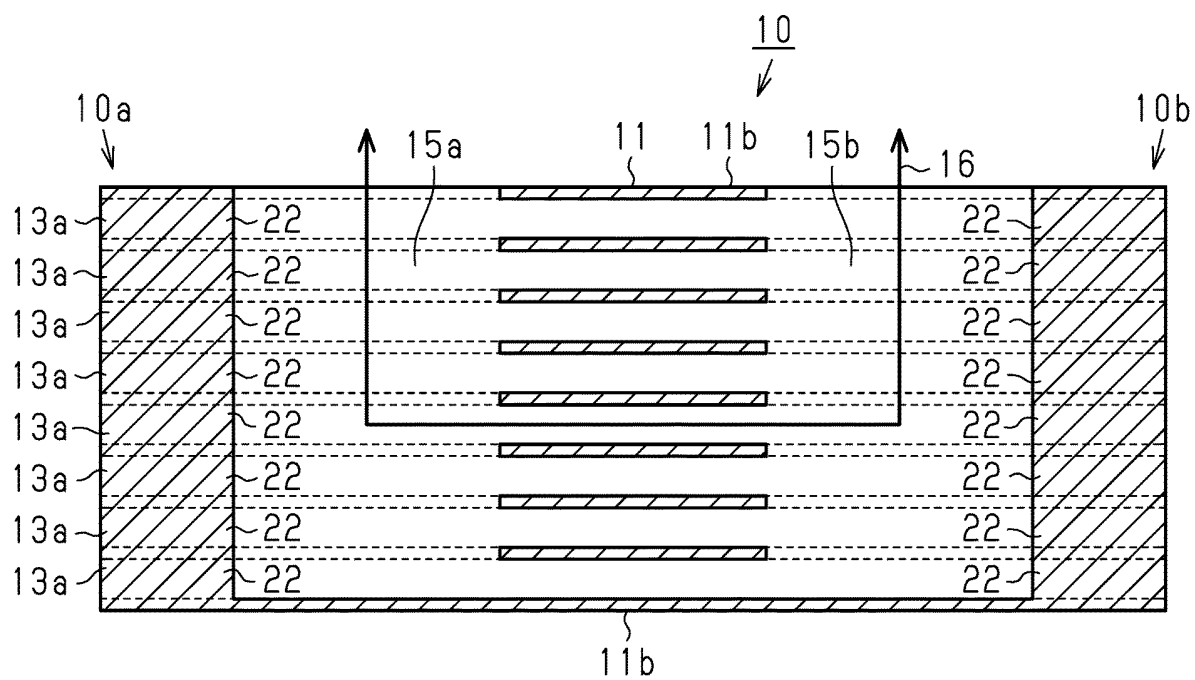


Fig.4

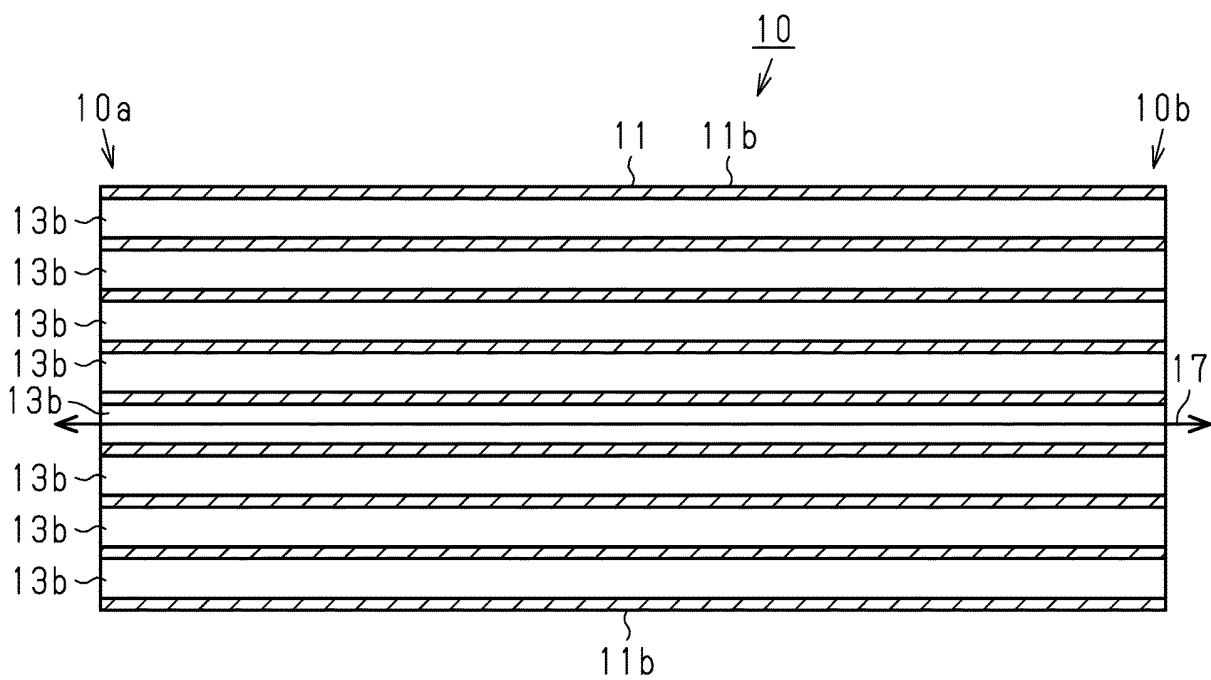


Fig.5

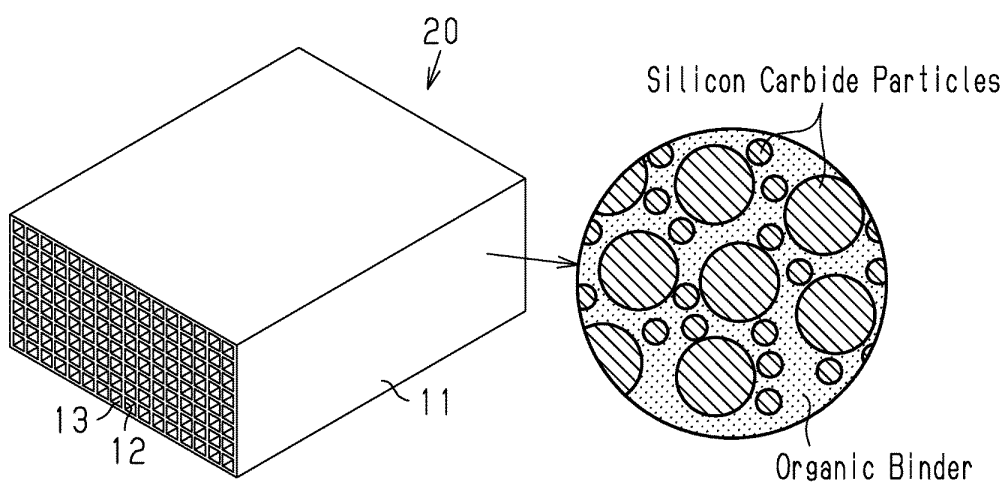


Fig.6

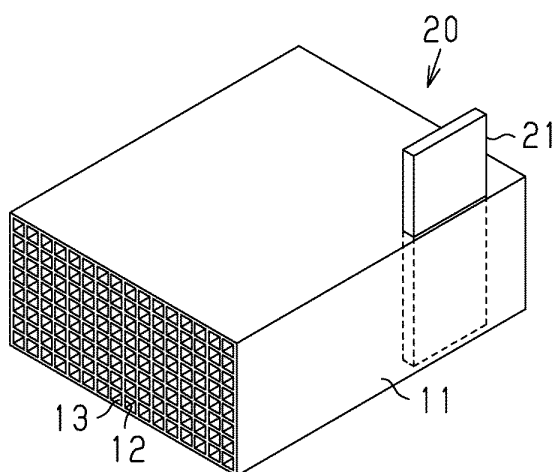


Fig.7

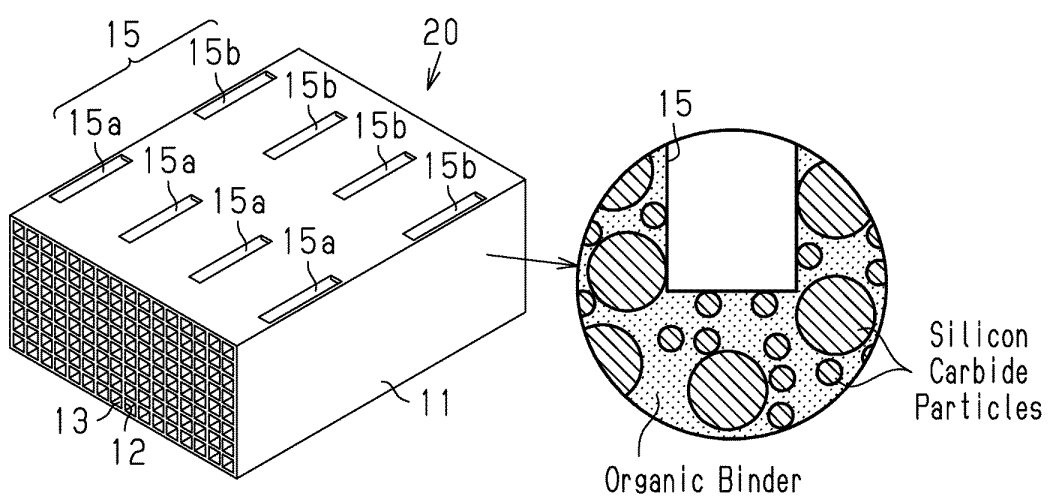


Fig.8

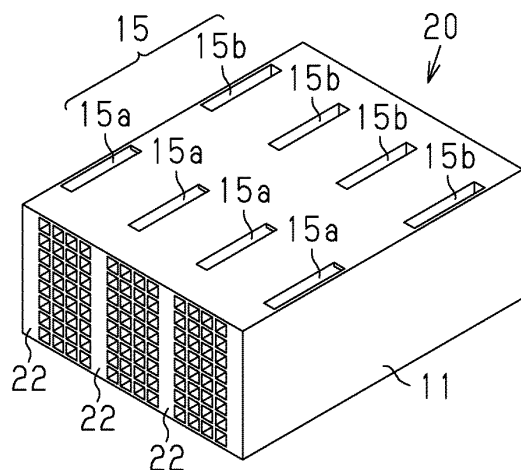


Fig.9

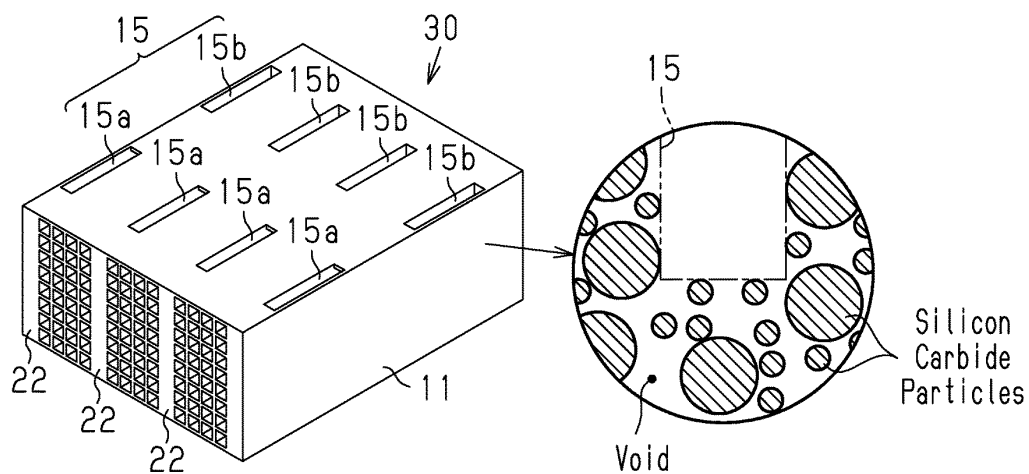


Fig.10

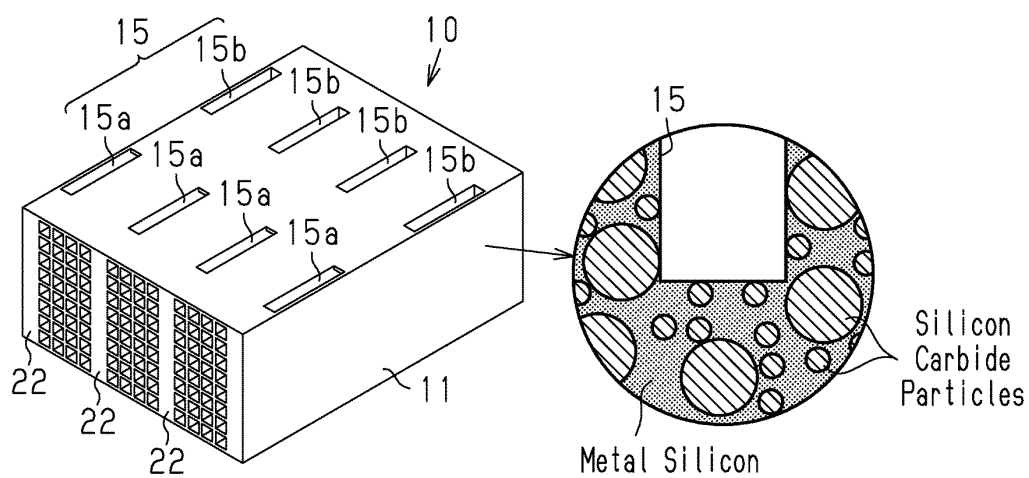


Fig.11

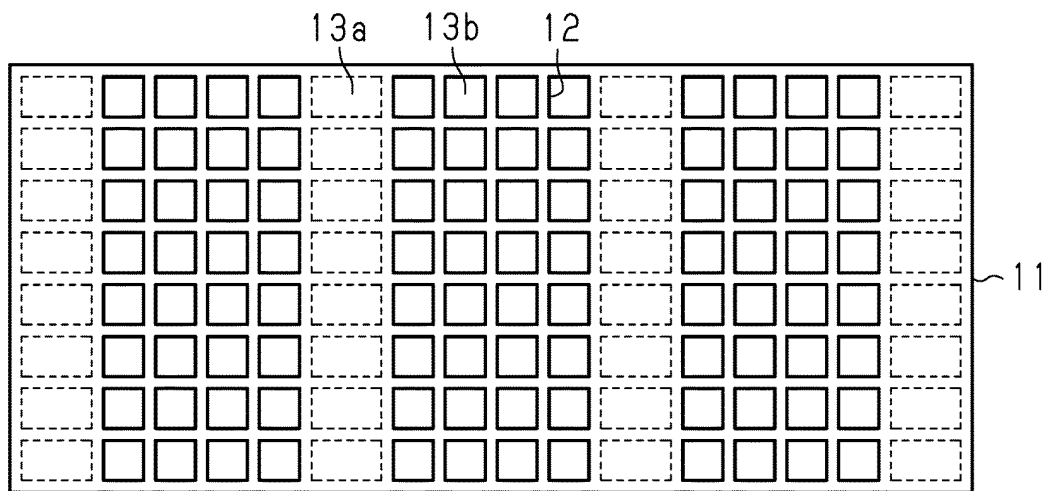


Fig.12

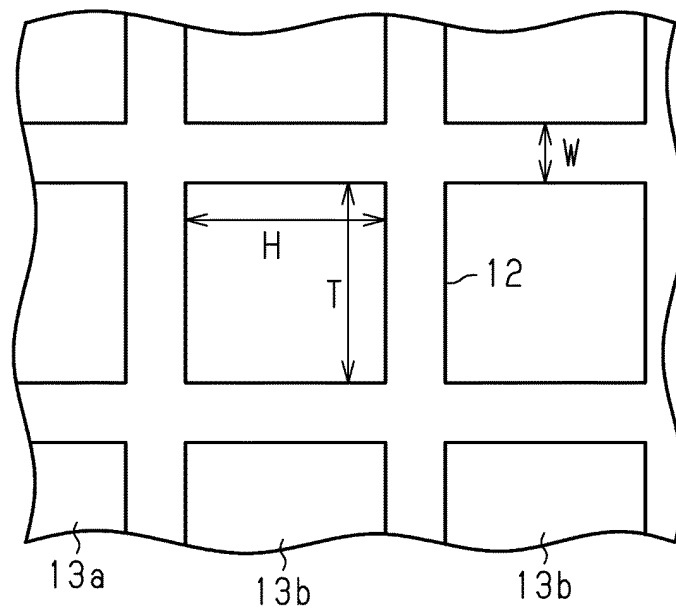


Fig.13

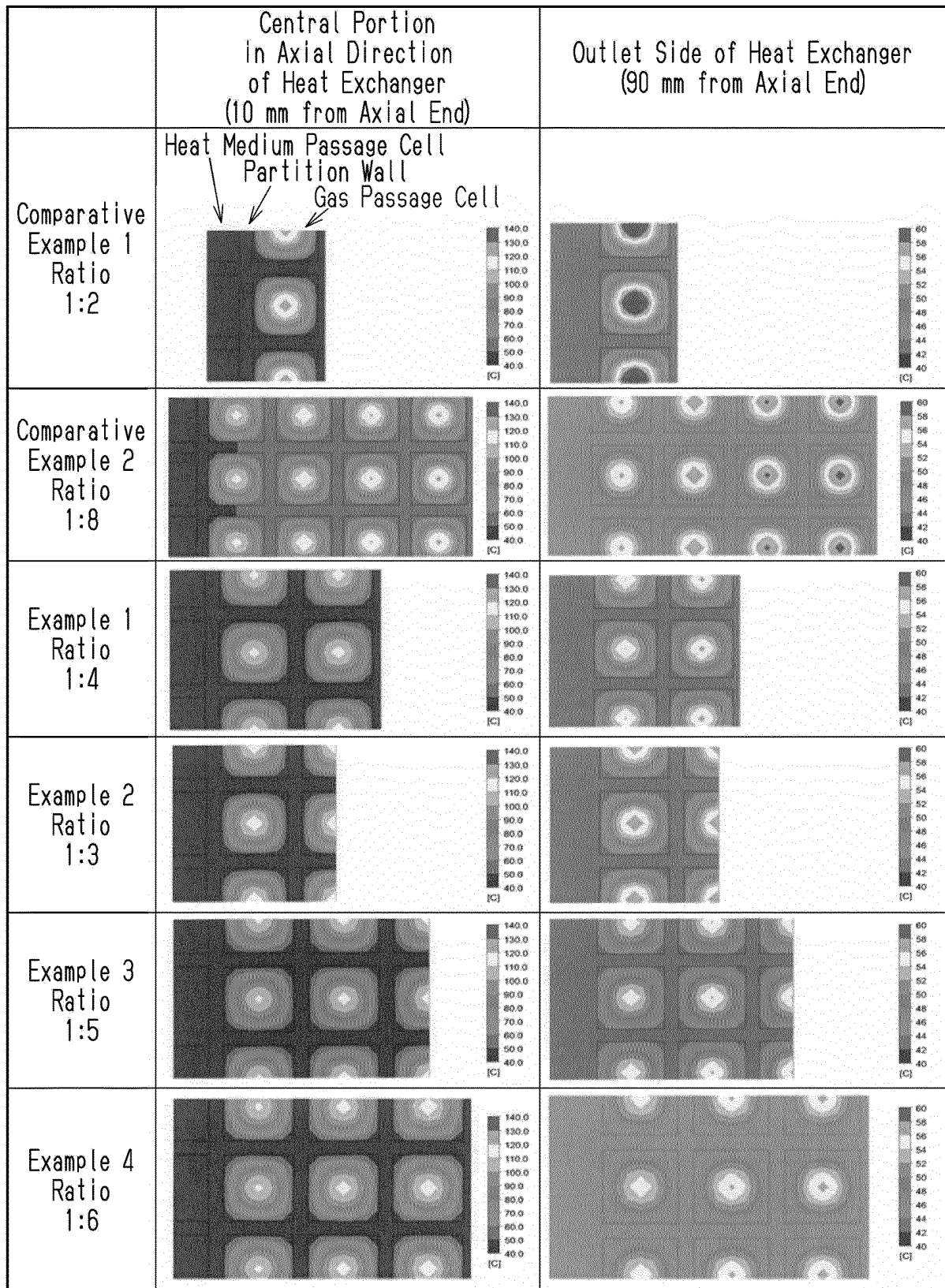
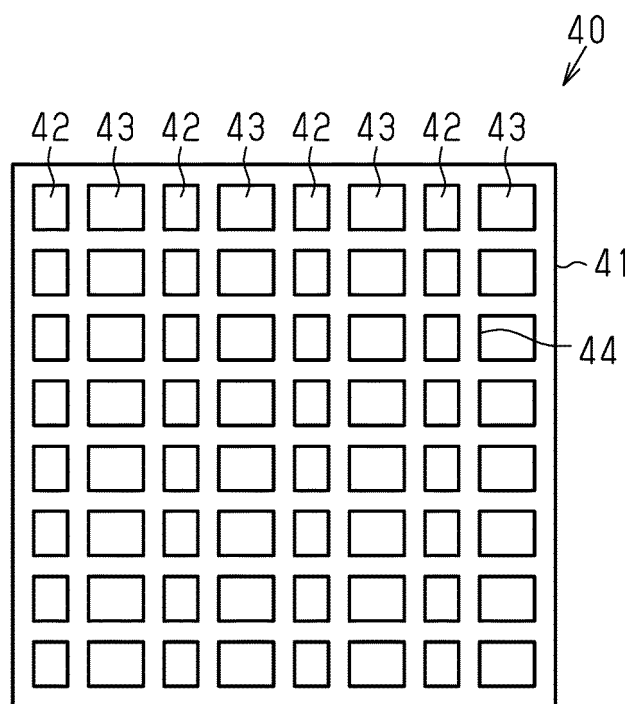


Fig.14



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2018/038572

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. F28D7/00 (2006.01) i, F01N5/02 (2006.01) i, F28D7/16 (2006.01) i,
F28F21/04 (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)

Int.Cl. F28D7/00, F01N5/02, F28D7/16, F28F21/04

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996

Published unexamined utility model applications of Japan 1971-2018

Registered utility model specifications of Japan 1996-2018

Published registered utility model applications of Japan 1994-2018

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.
Y	JP 2015-140959 A (IBIDEN CO., LTD.) 03 August 2015, paragraphs [0022], [0025], [0052]-[0062], fig. 2, 5, 7-8 & WO 2015/115256 A1	1-6
Y	WO 2013/132679 A1 (MITSUBISHI ELECTRIC CORP.) 12 September 2013, paragraph [0018], fig. 1-2, 8 & EP 2840342 A1 paragraph [0053], fig. 1-2, 8	1-6
Y	JP 61-285391 A (MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD.) 16 December 1986, fig. 1 (Family: none)	1-6

☐

Further documents are listed in the continuation of Box C.

☐

See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search
28 November 2018 (28.11.2018)

Date of mailing of the international search report
18 December 2018 (18.12.2018)

Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

Authorized officer

Telephone No.

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Patent documents cited in the description

- JP 2015140960 A [0004]