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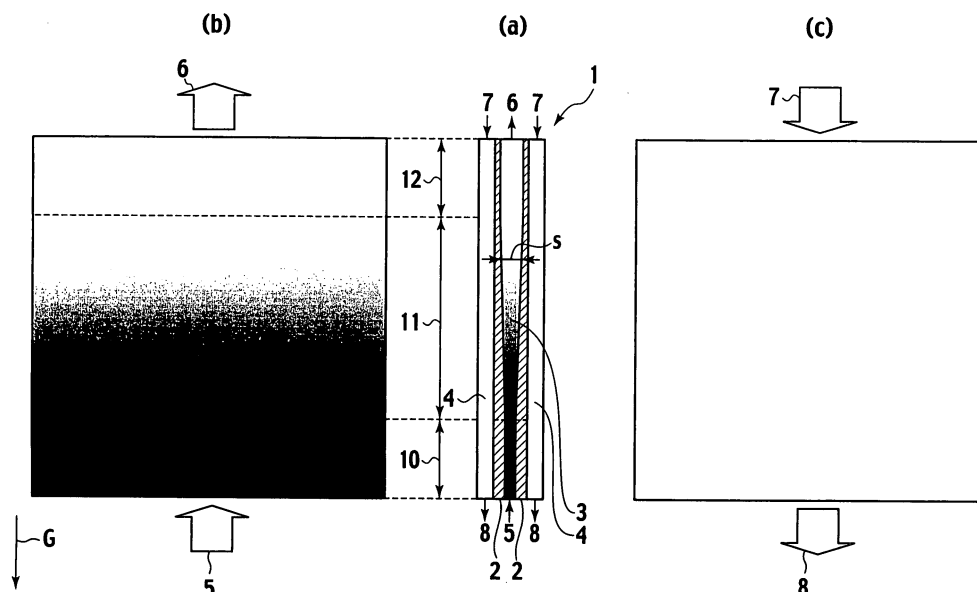
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(54) **MICROCHANNEL-TYPE EVAPORATOR AND SYSTEM USING THE SAME**

(57) In an evaporator 1, space between two heat transfer plates 2 opposite to each other serves as a liquid path 3, and the outsides of the heat transfer plates 2 serve as a gas path 4. At the lower end of the liquid path 3, a liquid inlet, through which liquid to be evaporated is supplied to the evaporator 1, is provided, and at the upper end of the liquid path 3, a vapor outlet is provided. The

liquid to be evaporated vaporizes while flowing from bottom to top. The heating gas is supplied from a gas inlet 7, which is provided at the upper end of the evaporator, and discharged from a gas outlet 8, which is provided at the lower end of the evaporator. Size of space S of the liquid path 3 gradually increases from bottom to top in a gas-liquid two phase region 11.

FIG. 1



Description

TECHNICAL FIELD

[0001] The present invention relates to a microchannel-type evaporator in which a path for a liquid to be evaporated is narrower than diameter of departing bubbles and to a system using the same.

BACKGROUND ART

[0002] In a fuel cell, fuel gas such as hydrogen and oxidant gas containing oxygen are electrochemically reacted through electrolyte, and electric energy is directly extracted from electrodes provided on both sides of the electrolyte. A polymer electrolyte fuel cell using a solid polymer electrolyte operates at low temperature and is easy to use. Accordingly, the polymer electrolyte fuel cell has attracted attention as a power supply for vehicles.

[0003] As a method of supplying hydrogen to the fuel cell, there are a method of directly supplying hydrogen from a hydrogen storage unit such as high-pressure hydrogen tank or a hydrogen storage alloy tank and a fuel reforming method of extracting hydrogen from fuel such as methanol or hydrocarbon and supplying the same. In the fuel reforming method, when the fuel is liquid, fuel or water is evaporated by an evaporator and then introduced to a fuel reformer, in which hydrogen is generated by a fuel reforming reaction.

[0004] As a small evaporator with high efficiency which is suitable for vehicles, an evaporator for air conditioning which evaporates refrigerant has been known (see Japanese Patent No. 2786728).

DISCLOSURE OF INVENTION

[0005] However, the conventional evaporator has a problem of reduction of heat exchange capability in a region of high heat flux. Hereinafter, such a problem is described.

(Definition of Microchannel)

[0006] In the present invention, the microchannel is defined as follows. A channel whose space is smaller than diameter of bubbles departing from heat transfer surface is defined as a microchannel. In other words, when bubbles which are yet smaller than departure diameter are crushed by walls of a channel to form microlayers between the bubbles and heating surfaces, such a channel is defined as a microchannel.

[0007] The diameter of bubbles having departed depends on a type of liquid to be evaporated, surface properties of heat transfer plates, and degree of superheat. Specifically, as shown in FIG. 19, when the liquid to be evaporated is water, the diameter is about 0.8 mm in the case of hydrophilic titanium oxide coating, and the diameter is about 2.5 mm in the case of hydrophobic silicone

coating. Accordingly, in the case of titanium oxide coating, the space size of the microchannel in the heating surfaces is set to not more than 0.8 mm. Note that the relation between degree of surface superheat and bubble diameter shown in FIG. 19 is for the case where the heat transfer surfaces are planar. Moreover, in polishing in the drawing, green carborundum of #2000 is used.

(Need for Formation of Thin Liquid Film on Heat Transfer Surface)

[0008] As for a parallel plate-type evaporator, FIG. 20A shows a relation between degree of superheat in the heat transfer surfaces and heat flux in cases where the space between the heat transfer surfaces is small and large. The case of small space between the heat transfer surfaces is indicated by a solid line, and the case of large space is indicated by a dashed line.

[0009] As shown in FIG. 20A, the two lines intersect with each other at a degree of superheat and a heat flux. When the space between the heat transfer surfaces is small, the evaporator exhibits good heat transfer characteristics in a region of low heat flux. However, the heat transfer characteristics are degraded in a region of high heat flux, and accordingly the critical heat flux (CHF) is reduced. On the contrary, when the space between the heat transfer surfaces is large, the heat transfer characteristics are good in the region of high heat flux but are degraded in the region of low heat flux.

[0010] The mechanism of such characteristics is conceived to be reduction of the heat transfer coefficient due to dryout of the heat transfer surfaces. FIG. 20B shows variations in flow and ways of heat transfer in an evaporation tube. Upper part in the drawing shows downstream of the evaporation tube, and lower part in the drawing shows upstream of the same. Liquid in the evaporation tube is substantially 100% in a liquid phase in the upstream but is in a two-phase state in the downstream in which the content of bubbles gradually increases in the liquid phase toward the downstream. In the downstream of the dryout position (post-dryout), the liquid to be evaporated does not exist on the heat transfer surfaces, and the heat transfer surfaces are completely dry. In a post-dryout dispersed flow region, since there is no liquid always in contact with the heat transfer surfaces, significant degradation of the heat transfer characteristics is shown.

[0011] FIG. 20C shows a relation between the heating heat flux and the heat transfer coefficient in the evaporation tube. In the drawing, the heat flux is higher in the order of A, B, C, and D. The drawing shows that as the heat flux increases, the region of the heat transfer coefficient reduced, or the dispersed flow region, moves to the upstream. In order to improve the reduction of the heat transfer coefficient, it is necessary to supply the liquid to be evaporated to the dispersed flow region and maintain the transfer heat surfaces to be wet.

[0012] FIG. 21 shows a boiling state of a microchannel in the high heat flux region. Lower part in the drawing

shows the upstream, and upper part shows the downstream. Liquid 106 to be evaporated is supplied from the upstream of a heat transfer surface 101, and vapor 107 is discharged to the downstream. The liquid 106 to be evaporated is heated by the heat transfer surface 101 into dispersed flow 105 in the downstream of a gas-liquid interface 104.

[0013] In the heat transfer surface 101, the gas-liquid interface 104 as an interface between a wet region in the upstream of the dryout position and a dispersed flow region 103 moves toward the upstream as the heat flux increases. Accordingly, when the heat flux is increased, the wet region 102, where heat transfer is effectively performed, is reduced, so that the heat exchange efficiency of the entire heat transfer surfaces is reduced. In order to increase the heat exchange efficiency, it is necessary to increase the proportion of the wet region 102 having high heat transfer efficiency in the heat transfer surface.

[0014] FIG. 22 shows states of boiling at heat fluxes of 9, 14, and 19 kW/m². As shown in FIG 22, along with an increase in heat flux, the wet area in the heat transfer surfaces decreases. Arrows in the drawing indicate the downstream direction.

[0015] FIG. 23A shows the heat transfer coefficient to a quality of the liquid to be evaporated, and FIG. 23B shows the critical heat flux to the quality of the liquid to be evaporated. As shown in FIG. 23A, in order to increase the heat transfer coefficient of the evaporator, the heat transfer surfaces need to maintain a wet region with a quality smaller than that at a dryout point A (quality X_a). As shown in FIG. 23B, the heat flux at the boundary between the pre-dryout region and the post-dryout region slopes down from left to right with respect to an increase in a quality. A heat flux corresponding to the quality X_a is q_{ca} , and the heat flux needs to be controlled so as to be smaller than this value.

[0016] The present invention was made in the light of the aforementioned problem, and an object of the invention is to increase the heat exchange efficiency of a microchannel-type evaporator and reduce the size thereof.

[0017] To achieve aforementioned object, a microchannel-type evaporator according to an aspect of the present invention includes a path provided substantially vertically, through which a liquid to be evaporated passes, and is characterized in that a space size of the path is smaller than diameters of bubbles departing from a heat transfer surface of the path, and the space size of the path in a gas-liquid two phase region is a minimum size satisfying that a heat flux is not more than a critical heat flux with respect to a quality.

BRIEF DESCRIPTION OF DRAWINGS

[0018]

FIG. 1(a) is a cross-sectional view showing a configuration of Embodiment 1 of a microchannel-type evaporator according to the present invention. FIG.

1 (b) is a conceptual view showing a liquid path of the microchannel-type evaporator of Embodiment 1. FIG. 1(c) is a conceptual view showing a heating gas path of the microchannel-type evaporator of Embodiment 1.

FIG. 2 is a graph for explaining a critical heat flux and a heat flux with respect to a quality in Embodiment 1.

FIG. 3(a) is a cross-sectional view showing a configuration of Embodiment 2 of the microchannel-type evaporator according to the present invention. FIG. 3(b) is a conceptual view showing a liquid path of the microchannel-type evaporator of Embodiment 2. FIG. 3(c) is a conceptual view showing a heating gas path of the microchannel-type evaporator of Embodiment 2.

FIG. 4 is a graph for explaining a critical heat flux and a heat flux with respect to a quality in Embodiment 2.

FIG. 5(a) is a cross-sectional view showing a configuration of Embodiment 3 of the microchannel-type evaporator according to the present invention. FIG. 5(b) is a conceptual view showing a liquid path of the microchannel-type evaporator of Embodiment 3. FIG. 5(c) is a conceptual view showing a heating gas path of the microchannel-type evaporator of Embodiment 3.

FIG. 6 is a graph for explaining a critical heat flux and a heat flux with respect to a quality in Embodiment 3.

FIG. 7(a) is a cross-sectional view showing a configuration of Embodiment 4 of the microchannel-type evaporator according to the present invention. FIG. 7(b) is a conceptual view showing a liquid path of the microchannel-type evaporator of Embodiment 4. FIG. 7(c) is a conceptual view showing a heating gas path of the microchannel-type evaporator of Embodiment 4. FIG. 7(d) is a cross-sectional view taken along a line VIId-VIIId in FIG. 7(b).

FIG. 8 is a graph for explaining a critical heat flux and a heat flux with respect to a quality in Embodiment 4.

FIG. 9(a) is a cross-sectional view showing a configuration of Embodiment 5 of the microchannel-type evaporator according to the present invention. FIG. 9(b) is a conceptual view showing a liquid path of the microchannel-type evaporator of Embodiment 5. FIG. 9(c) is a conceptual view showing a heating gas path of the microchannel-type evaporator of Embodiment 5.

FIG. 10(a) is a cross-sectional view showing a configuration of Embodiment 6 of the microchannel-type evaporator according to the present invention. FIG. 10(b) is a conceptual view showing a liquid path of the microchannel-type evaporator of Embodiment 6. FIG 10(c) is a conceptual view showing a heating gas path of the microchannel-type evaporator of Embodiment 6.

FIG. 11 (a) is a cross-sectional view showing a configuration of Embodiment 7 of the microchannel-type evaporator according to the present invention. FIG. 11(b) is a conceptual view showing a liquid path of the microchannel-type evaporator of Embodiment 7. FIG. 11(c) is a conceptual view showing a heating gas path of the microchannel-type evaporator of Embodiment 7.

FIG. 12(a) is a cross-sectional view showing a configuration of Embodiment 8 of the microchannel-type evaporator according to the present invention. FIG. 12(b) is a conceptual view showing a liquid path of the microchannel-type evaporator of Embodiment 8. FIG. 12(c) is a conceptual view showing a heating gas path of the microchannel-type evaporator of Embodiment 8.

FIG. 13 is a graph for explaining a critical heat flux and a heat flux with respect to quality in Embodiment 8.

FIG. 14 is a graph showing a relation between an inlet condition of pure water and a boiling region based on the characteristics of FIG. 13.

FIG. 15 is a schematic view showing a heating gas flow pattern of Case A in a system of Embodiment 8.

FIG. 16 is a schematic view showing a heating gas flow pattern of Case B in the system of Embodiment 8.

FIG. 17 is a schematic view showing a heating gas flow pattern of Case C in the system of Embodiment 8.

FIG. 18(a) is a schematic view showing the heating gas flow pattern of Case A. FIG. 18(b) is a schematic view showing the heating gas flow pattern of Case B. FIG. 18(c) is a schematic view showing a heating gas flow pattern of Case C.

FIG. 19 is a graph showing diameter of departing bubbles depending on surface properties of a heat transfer surface and degree of surface superheat.

FIG. 20A is a graph for explaining a relation between degree of superheat and heat flux in the microchannel-type evaporator.

FIG. 20B is a view for explaining variations in flow and heat transfer ways in an evaporation tube.

FIG. 20C is a graph for explaining a relation between a heating heat flux and a heat transfer coefficient.

FIG. 21 is a view showing a boiling state of the microchannel in a high heat flux region.

FIG. 22 graphically shows photographs of boiling states at heat fluxes of 9, 14, and 19 kW/m².

FIG. 23A is a graph showing the heat transfer coefficient with respect to a quality.

FIG. 23B is a graph showing a critical heat flux with respect to a quality.

BEST MODE FOR CARRYING OUT THE INVENTION

[0019] With reference to the drawings, a description is given of embodiments of a microchannel-type evaporator

according to the present invention in detail. The evaporator according to the present invention, which is not particularly limited, is suitable for an evaporator which evaporates water or hydrocarbon type fuel and supplies the same to a fuel reformer for a fuel cell.

(Embodiment 1)

[0020] FIGS. 1(a), 1(b), and 1(c) show a basic constituent unit of Embodiment 1 of the evaporator according to the present invention.

[0021] An evaporator 1 in this embodiment includes two heat transfer plates 2 opposite to each other. Between the heat transfer plates 2, a path 3 through which liquid to be evaporated passes is provided. The path 3 through which liquid to be evaporated passes is placed vertically, that is, along the direction G of gravity force. In the present invention, vertically setting the liquid path means setting the liquid path at such an angle that heat transfer properties in the right and left heat transfer surfaces which form a microchannel do not significantly lose symmetry because of the inclination thereof and, for example, includes setting the same at an angle of $\pm$ about 20 degrees from the vertical.

[0022] Furthermore, in the outside of the heat transfer plates 2, paths 4 through which heating gas passes, is provided. To form a real evaporator, it is preferable that the evaporator has a structure in which a plurality of the basic constituent units shown in the drawing are arranged in parallel. In this description, the path 3 through which the liquid to be evaporated passes is abbreviated as the liquid path 3, and the path 4 through which the heating gas passes is abbreviated as the gas path 4.

[0023] At the lower end of the liquid path 3, a liquid inlet 5, through which the liquid to be evaporated is supplied to the evaporator 1, is provided. At the upper end of the liquid path 3, a vapor outlet 6 is provided. The liquid to be evaporated evaporates as flowing from the bottom to the top of the evaporator 1. On the other hand, the heating gas is supplied from gas inlets 7, which are provided at the upper end of the evaporator, and discharged from gas outlets 8, which are provided at the lower end of evaporator. The evaporator of Embodiment 1 is therefore a countercurrent flow type evaporator in which the flow directions of the liquid to be evaporated and the heating gas are opposite to each other. During operation of the evaporator 1, the inside of the liquid path 3 is composed of a liquid phase region 10, a gas-liquid two phase region 11, and a gas phase region 12 sequentially from the bottom.

[0024] Size of space S of the liquid path 3 gradually increases from the bottom to the top in the gas-liquid two phase region 11.

[0025] Material of the heat transfer plates 2 can be a corrosion-resistant metal, for example, stainless steel, titanium, and titanium alloy.

[0026] Furthermore, the surface of each heat transfer plate 2 is coated with titanium oxide or the like for hy-

drophilic treatment. This can provide higher capillary pressure and more penetration into the heating surfaces, thus further increasing the critical heat flux.

[0027] In this embodiment, the mass flow rate of the heating gas is sufficiently higher than that of the liquid to be evaporated, and there is almost no change in temperature of the heating gas between the gas inlets 7 and the gas outlets 8.

[0028] FIG. 2 shows relations between the quality and the critical heat flux or heat flux according to variations in the space S of the liquid path 3 in the gas-liquid two phase region 11. The horizontal axis of FIG. 2 represents the quality as a mass ratio of vapor and a mixture of gas and liquid which exist in the evaporation tube. The vertical axis of FIG. 2 represents heat flux q and critical heat flux q_c (kW/m²). A quality of 0 indicates that all the liquid to be evaporated is in a liquid state, and a quality of 1 indicates that all the liquid to be evaporated is in a gas state.

[0029] The gas-liquid two phase region 11 of FIGS. 1 (a) and 1(b) can be considered to be a region in which the quality is 0 and 1 at the lower and upper ends, respectively, and gradually increases therebetween.

[0030] When such quality and critical heat flux are represented by the horizontal and vertical axes, respectively, the correlation between the quality X and the critical heat flux q_c in cases of spaces S_A , S_B , and S_C ($S_A > S_B > S_C$) of the path of the liquid to be evaporated in the parallel plate microchannel-type evaporator is shown as FIG. 2.

[0031] When the entire evaporation tube has a same space, in part of smaller quality, the ratio of liquid is high, and a larger amount of heat is transferred from the heat transfer plates. Accordingly, the critical heat flux tends to be higher. When the space size of the evaporation tube is increased, a larger amount of the liquid to be evaporated is held in the space, and the critical heat flux tends to increase.

[0032] Herein, when the path space is increased with respect to the path space S_B as a criterion, the critical heat flux increases, and the rate of the increase is higher when the quality is smaller. On the contrary, when the path space is reduced, the critical heat flux is reduced, and the rate of the reduction is higher when the quality is smaller.

[0033] In this embodiment, it is assumed that the mass flow rate of the heating gas is sufficiently higher than that of the liquid to be evaporated and there is almost no change in temperature of the heating gas between the gas inlets 7 and the gas outlets 8. The heat flux given from the heating gas through the heat transfer plates to the liquid to be evaporated is therefore constant regardless of the quality and is indicated by a dashed line of FIG. 2. The dashed line indicating the heat flux and a line indicating the critical heat flux of the path space S_B intersect with each other at a quality X_B . In other words, the graph shows that the critical heat flux is supplied at the position of the quality X_B of the evaporator with the path space S_B . In a region with a quality of not less than the quality X_B , supplied heat flux exceeds the critical heat

flux, so that the heat transfer surfaces change from the wet state to the dry state. When the heat transfer surfaces change to the dry state, the heat transfer coefficient is reduced. Accordingly, the heat flux is drastically reduced as indicated by a chain line of FIG. 2.

[0034] In this embodiment, to avoid such reduction of heat flux, in the region with a quality X of not less than X_B , the path space is increased to $S_{B+1_case\ 1}$, $S_{B+2_case\ 1}$, and $S_{B+3_case\ 1}$ as the quality increases to X_{B+1} , X_{B+2} , and X_{B+3} . This can prevent the heat flux from exceeding the critical heat flux even if the quality becomes larger than X_B , thus providing a maximum heat transfer coefficient.

[0035] In a similar way, in a region with a quality X of not more than X_B , even if the path space is reduced to $S_{B-1_case\ 1}$ and $S_{B-2_case\ 1}$ as the quality decreases to X_{B-1} and X_{B-2} , the heat transfer surfaces can be maintained to be wet. The heat flux can be therefore within the critical heat flux even if the quality becomes smaller than X_B , thus providing a maximum heat transfer coefficient.

[0036] As described above, in the microchannel-type evaporator of countercurrent flow type of the present invention, the space S of the liquid path is set to a minimum space size satisfying that heat flux is not more than the critical heat flux according to the quality X , so that thin liquid films of the liquid to be evaporated is formed on part of the heat transfer surfaces which comes into contact with the gas-liquid two phase region of the liquid path. The part of the heat transfer surfaces which comes into contact with the gas-liquid two phase region can be therefore always maintained to have a high transfer coefficient. Accordingly, the heat exchange efficiency of the microchannel-type evaporator can be increased, and moreover the microchannel-type evaporator can be reduced in size.

(Embodiment 2)

[0037] FIGS. 3(a), 3(b), and 3(c) show a basic constituent unit of Embodiment 2 of the evaporator according to the present invention.

[0038] The configuration of the evaporator 1 itself of Embodiment 2 is, similar to the configuration of the evaporator of Embodiment 1, of the countercurrent flow type in which the flow directions of the liquid to be evaporated and the heating gas are opposite to each other. This embodiment is an embodiment in the case where the mass flow rate of the heating gas is not negligible compared to that of the liquid to be evaporated and the temperature of the heating gas decreases from the gas inlets 7 to the gas outlets 8.

[0039] FIG. 4 shows a change (a dashed line) in heat flux from the heating gas to the liquid to be evaporated and critical heat flux of each path space in this embodiment. As indicated by the dashed line of FIG. 4, the heat flux is low where the quality is small, and the heat flux is high where the quality is large. This is because the fol-

lowing reason: where the quality is large, the temperature of the heating gas is high and the difference in temperature between the heating gas and the liquid to be evaporated is large, so that the heat flux is high; and where the quality is small, the temperature of the heating gas decreases and the difference in temperature between the heating gas and the liquid to be evaporated is small, so that the heat flux is low.

[0040] In FIG. 4, the dashed line indicating the heat flux q given from the heating gas to the liquid to be evaporated and a line indicating the critical heat flux q_c of the path space S_B intersect with each other at a quality X_B . The graph shows that the critical heat flux is supplied at the position of the quality X_B of the evaporator with the path space S_B . In the region with a quality of not less than the quality X_B , supplied heat flux exceeds the critical heat flux, so that the heat transfer surfaces change from the wet state to the dry state. When the heat transfer surfaces change to the dry state, the heat transfer coefficient is reduced. Accordingly, the heat flux is drastically reduced as indicated by a chain line of FIG. 4.

[0041] In this embodiment, to avoid such reduction of heat flux, in the region with a quality X of not less than X_B , the path space is increased to $S_{B+1_case\ 2}$, $S_{B+2_case\ 2}$, and $S_{B+3_case\ 2}$ as the quality increases to X_{B+1} , X_{B+2} , and X_{B+3} . This can prevent the heat flux from exceeding the critical heat flux even if the quality becomes more than X_B , thus providing a maximum heat transfer coefficient.

[0042] In a similar manner, in a region with a quality X of not more than X_B , even if the path space is reduced to $S_{B-1_case\ 2}$ and $S_{B-2_case\ 2}$ as the quality decreases to X_{B-1} and X_{B-2} , the heat transfer surfaces can be maintained to be wet. The heat flux can be therefore at the critical heat flux even if the quality becomes less than X_B , thus providing a maximum heat transfer coefficient.

[0043] As described above, in the microchannel-type evaporator of countercurrent flow-type of the present invention, the space S of the liquid path is set to a minimum space size satisfying that heat flux is not more than the critical heat flux according to the quality X , so that thin liquid films of the liquid to be evaporated are formed on part of the heat transfer surfaces which comes into contact with the gas-liquid two phase region of the liquid path. The part of the heat transfer surfaces which comes into contact with the gas-liquid two phase region can be therefore always maintained to have a high transfer coefficient. Accordingly, the heat exchange efficiency of the microchannel-type evaporator can be increased, and moreover the microchannel-type evaporator can be reduced in size.

(Embodiment 3)

[0044] FIGS. 5(a), 5(b), and 5(c) show a basic constituent unit of Embodiment 3 of the evaporator according to the present invention.

[0045] As shown in FIG. 5(a), an evaporator 1 in this

embodiment is an embodiment in which space between two opposite heat transfer plates 2 serves as a liquid path 3. Sections outside of the heat transfer plates 2 serve as gas paths 4. To form a real evaporator, it is preferable that the evaporator has a structure in which a plurality of the basic constituent units shown in the drawing are arranged in parallel.

[0046] At the lower end of the liquid path 3, a liquid inlet 5, through which the liquid to be evaporated is supplied to the evaporator 1, is provided. At the upper end of the liquid path, a vapor outlet 6 is provided. The liquid to be evaporated evaporates as flowing from the bottom to the top of the evaporator 1. On the other hand, the heating gas is supplied from gas inlets 7, which are provided at the lower end of the evaporator, and discharged from gas outlets 8, which are provided at the upper end of evaporator. Accordingly, the evaporator of this embodiment is a same flow direction type evaporator in which the flow directions of the liquid to be evaporated and the heating gas are substantially in a same direction. During operation of the evaporator 1, the inside of the liquid path 3 is composed of a liquid phase region 10, a gas-liquid two phase region 11, and a gas phase region 12 sequentially from the bottom.

[0047] Size of space S of the liquid path 3 gradually decreases from the bottom to the top in the gas-liquid two phase region 11.

[0048] Material of the heat transfer plates 2 can be a corrosion-resistant metal, for example, stainless steel, titanium, and titanium alloy.

[0049] Furthermore, the surface of each heat transfer plate 2 which comes into contact with the liquid to be evaporated is coated with titanium oxide or the like for hydrophilic treatment. This can provide higher capillary pressure and more penetration into the heating surfaces, thus further increasing the critical heat flux.

[0050] This embodiment is an embodiment in the case where the mass flow rate m (g/s) of the heating gas is not negligible compared to that of the liquid to be evaporated and the temperature of the heating gas decreases from the gas inlets 7 toward the gas outlets 8.

[0051] FIG. 6 shows a change (a dashed line) in heat flux q from the heating gas to the liquid to be evaporated and critical heat flux q_c of each path space in this embodiment. As indicated by the dashed line of FIG. 6, the heat flux is high where the quality is small, and the heat flux is low where the quality is large. This is because the following reason: where the quality is small, the temperature of the heating gas is high and the difference in temperature between the heating gas and the liquid to be evaporated is large, so that the heat flux is high; and where the quality is small, the temperature of the heating gas is reduced and the difference in temperature between the heating gas and the liquid to be evaporated is small, so that the heat flux is small.

[0052] In FIG. 6, the dashed line indicating the heat flux q given from the heating gas to the liquid to be evaporated and a line indicating the critical heat flux q_c of the

path space S_B intersect with each other at a quality X_B . The graph shows that the critical heat flux is supplied at the position of the quality X_B of the evaporator with the path space S_B . In the region with a quality of not less than the quality X_B , heat flux supplied exceeds the critical heat flux, so that the heat transfer surfaces change from the wet state to the dry state. When the heat transfer surfaces change to the dry state, the heat transfer coefficient is reduced. Accordingly, the heat flux is drastically reduced as indicated by a chain line of FIG. 6.

[0053] To avoid such reduction of heat flux, in the region with a quality X of not more than X_B , the path space is increased to $S_{B-1_case\ 3}$ and $S_{B-2_case\ 3}$ as the quality decreases to X_{B-1} and X_{B-2} . This can prevent the heat flux from exceeding the critical heat flux even if the quality becomes smaller than X_B , thus providing a maximum heat transfer coefficient.

[0054] In a similar manner, in the region with a quality X of not less than X_B , the path space is reduced to $S_{B+1_case\ 3}$, $S_{B+2_case\ 3}$, and $S_{B+3_case\ 3}$ as the quality increases to X_{B+1} , X_{B+2} , and X_{B+3} , the heat transfer surfaces can be maintained to be wet. Accordingly, the heat flux can be maintained within the critical heat flux even if the quality becomes smaller than X_B , thus providing a maximum heat transfer coefficient.

[0055] As described above, in the microchannel-type evaporator of the same flow direction type of the present invention, the space S of the liquid path is set to a minimum space size satisfying that heat flux is not more than the critical heat flux according to the quality X , so that thin liquid films of the liquid to be evaporated are formed on part of the heat transfer surfaces which comes into contact with the gas-liquid two phase region of the liquid path. The part of the heat transfer surfaces which comes into contact with the gas-liquid two phase region can be therefore always maintained to have a high transfer coefficient. Accordingly, the heat exchange efficiency of the microchannel-type evaporator can be increased, and moreover the microchannel-type evaporator can be reduced in size.

(Embodiment 4)

[0056] FIGS. 7(a), 7(b), and 7(c) show a basic constituent unit of Embodiment 4 of the evaporator according to the present invention.

[0057] As shown in FIG. 7(a), an evaporator 1 in this embodiment is an embodiment in which space between two opposite heat transfer plates 2 serves as a liquid path 3. Sections outside of the heat transfer plates 2 serve as gas paths 4. To form a real evaporator, it is preferable that the evaporator has a structure in which a plurality of the basic constituent units shown in the drawing are arranged in parallel.

[0058] At the lower end of the liquid path 3, a liquid inlet 5, through which the liquid to be evaporated is supplied to the evaporator 1, is provided. At the upper end of the liquid path, a vapor outlet 6 is provided. The liquid

to be evaporated evaporates as flowing from the bottom to the top of the evaporator 1. On the other hand, the heating gas is supplied from gas inlets 7, which are provided at the right end of the evaporator, and discharged from gas outlets 8, which are provided at the left end of the evaporator. The evaporator of this embodiment is therefore a cross flow type evaporator in which the flow directions of the liquid to be evaporated and the heating gas are orthogonal to each other. During operation of the evaporator 1, the inside of the liquid path 3 is composed of a liquid phase region 10, a gas-liquid two phase region 11, and a gas phase region 12 sequentially from the bottom.

[0059] Size of space S of the liquid path 3 changes three dimensionally so as to gradually decrease from the bottom to the top in the gas-liquid two phase region 11 and gradually decrease from the right to the left.

[0060] Material of the heat transfer plates 2 can be a corrosion-resistant metal, for example, stainless steel, titanium, and titanium alloy.

[0061] Furthermore, the surface of each heat transfer plate 2 which comes into contact with the liquid to be evaporated is coated with titanium oxide or the like for hydrophilic treatment. This can provide higher capillary pressure and more penetration into the heating surfaces, thus further increasing the critical heat flux.

[0062] FIG. 8 shows changes (dashed lines) in heat flux from the heating gas to the liquid to be evaporated at a position L-L in the upstream of the heating gas, a position M-M in the center of the evaporator 1, and a position N-N in the downstream of the heating gas and critical heat flux of each path space.

[0063] In this embodiment, the heat flux transferred from the heating gas to the liquid to be evaporated in the evaporator is the highest at the position L-L in the upstream of the heating gas and decreases along with a decrease in temperature of the heating gas toward the position M-M in the middle of the stream and the position N-N in the downstream. In this embodiment, similar to Embodiment 1, it is assumed that the mass flow rate of the heating gas is sufficiently higher than that of the liquid to be evaporated and there is almost no change in temperature of the heating gas between the gas inlets 7 and the gas outlets 8. The heat flux given from the heating gas through the heat transfer plates to the liquid to be evaporated is therefore constant regardless of the quality and is indicated by a dashed line of FIG. 8.

[0064] In FIG. 8, the dashed line indicating the heat flux q given from the heating gas to the liquid to be evaporated at the position M-M and a line indicating the critical heat flux q_c of the path space S_B intersect with each other at a quality X_B . In other words, the graph shows that the critical heat flux is supplied at the position of the quality X_B of the evaporator with the path space S_B . In the region with a quality of not less than the quality X_B , supplied heat flux exceeds the critical heat flux. The heat transfer surfaces therefore change from the wet state to the dry state, and the heat transfer coefficient is reduced. Ac-

cordingly, the heat flux is drastically decreased in a similar manner to Embodiment 2, which is not shown in the drawing.

[0065] In this embodiment, to avoid such reduction of heat flux, in a region with a quality X of not less than X_B at the position M-M, the path space is increased to S_{B+1} , S_{B+2} , and S_{B+3} as the quality increases to X_{B+1} , X_{B+2} , and X_{B+3} . The heat flux can be therefore prevented from exceeding the critical heat flux even if the quality becomes larger than X_B , thus providing a maximum heat transfer coefficient. In the region of a quality X of not more than X_B , even if the path space is reduced to $S_{B-1_case\ 3}$ and $S_{B-2_case\ 3}$ as the quality decreases to X_{B-1} and X_{B-2} , the heat transfer surfaces can be maintained to be wet. Accordingly, the heat flux can be maintained within the critical heat flux even if the quality becomes smaller than X_B , thus providing a maximum heat transfer coefficient..

[0066] In a similar manner, the dashed line indicating the heat flux given from the heating gas to the liquid to be evaporated at the position L-L of the evaporator 1 and a line indicating the critical heat flux of the path space S_A intersect with each other at a quality X_A . In other words, the graph shows that the critical heat flux is supplied at the position of the quality X_A of the evaporator with the path space S_A . The critical heat flux is supplied at the position of the quality X_A of the path space S_A , and in the region with a quality of not less than the quality X_A , supplied heat flux exceeds the critical heat flux. The heat transfer surfaces therefore change from the wet state to the dry state, and the heat transfer coefficient is reduced. Accordingly, the heat flux is drastically reduced in a similar manner to Embodiment 2, which is not shown in the drawing.

[0067] To avoid such reduction of heat flux, in the region with a quality X of not less than X_A at the position L-L, the path space is increased as the quality increases to X_{A+1} , X_{A+2} , and X_{A+3} . This can prevent the heat flux from exceeding the critical heat flux even if the quality becomes larger than X_A , thus providing a maximum heat transfer coefficient. In a region with a quality X of not more than X_A , even if the path space is reduced as the quality decreases to X_{A-1} and X_{A-2} , the heat transfer surfaces can be maintained to be wet. The heat flux can be therefore within the critical heat flux even if the quality becomes smaller than X_A , thus providing a maximum heat transfer coefficient.

[0068] In this embodiment, the same process as the processes performed for the positions L-L and M-M is performed across the entire region of the evaporator 1. The space size can be thus set to a minimum space size that allows the heat flux to be not more than the critical heat flux according to the quality X .

[0069] As described above, in the microchannel-type evaporator of the cross flow type, the space S of the liquid path is set to the minimum space size satisfying that the heat flux is not more than the critical heat flux according to the quality X , so that thin liquid films of the liquid to be evaporated are formed on part of the heat transfer sur-

faces which comes into contact with the gas-liquid two phase region of the liquid path. The part of the heat transfer surfaces which comes into contact with the gas-liquid two phase region can be therefore maintained to have a high transfer coefficient. Accordingly, the heat exchange efficiency of the microchannel-type evaporator can be increased, and moreover the microchannel-type evaporator can be reduced in size.

10 (Embodiment 5)

[0070] FIGS. 9(a), 9(b), and 9(c) show a basic constituent unit of Embodiment 5 as a modification of Embodiment 2.

15 **[0071]** A difference between the evaporator of this embodiment and the evaporator of Embodiment 2 is that the path space S is gradually reduced in the gas phase region 12 of the liquid path 3. The other configuration is the same as that of Embodiment 2. Same constituent components are given same numerals, and redundant description is omitted. This embodiment has an effect on preventing droplets of the liquid to be evaporated from being discharged from the vapor outlet 6.

20 **[0072]** Gradually decreasing the path space S in the gas-phase region 12 of the liquid path 3 like Embodiment 5 can be applied to not only Embodiment 2 but also other embodiments.

(Embodiment 6)

25 **[0073]** FIGS. 10(a), 10(b), and 10(c) show a basic constituent unit of Embodiment 6 of the evaporator according to the present invention.

30 **[0074]** An evaporator 1 of Embodiment 6 includes, in addition to the cross flow-type evaporator of Embodiment 4, a plurality of turning sections provided with partitions 9 in a heating gas path 4 to cause the heating gas to meander. The other configuration is the same as that of Embodiment 4. The same constituent components are given same numerals, and redundant description is omitted.

35 **[0075]** In Embodiment 4, the boundary line between the gas-phase region 12 and the gas-liquid two phase region 11 and the boundary line between the gas-liquid two phase region 11 and the liquid-phase region 10 are sloped. However, according to this embodiment, these boundary lines can be kept more parallel to the flow direction of the heating gas than those of Embodiment 4. Embodiment 6 therefore has an effect on further uniforming the superheat of vapor generated from the end of the vapor outlet 6.

(Embodiment 7)

40 **[0076]** FIGS. 11 (a), 11 (b), and 11 (c) show a basic constituent unit of Embodiment 6 as a modification of Embodiment 2.

[0077] An evaporator 1 of Embodiment 7 includes, in

addition to the cross flow-type evaporator of Embodiment 4, a plurality of turning sections provided with partitions 9 in a heating gas path 4 to cause the heating gas to meander. Furthermore, a difference between Embodiment 6 and Embodiment 7 is that the gas inlets 7 are in the vicinity of the liquid inlet 5 and the gas outlets 8 are in the vicinity of the vapor outlet 6. Accordingly, hottest part of the heating gas heats the liquid phase region 10, whose critical heat flux is highest, so that the space S of the liquid path 3 can be configured to be narrower than that of Embodiment 6. Embodiment 7 therefore has an effect that the evaporator 1 thereof can be smaller than that of Embodiment 6. The other configuration is the same as that of Embodiment 4. The same constituent components are given same numerals, and redundant description is omitted.

(Embodiment 8)

[0078] This embodiment is described using FIGS. 12 to 18. FIGS. 12(a), 12(b), and 12(c) show a basic constituent unit of Embodiment 8 of the evaporator according to the present invention. FIG. 13 shows a characteristic of the critical heat flux under inlet conditions of pure water as the liquid to be evaporated and high temperature gas in the evaporator shown in FIG. 12. FIG. 14 shows a relation between the inlet condition of the pure water and the boiling region based on the characteristic of FIG. 13. FIGS. 15 to 17 show flow patterns of the heating gas when the evaporator is controlled based on a map of FIG. 14.

[0079] As shown in FIG. 12, an evaporator 1 is an evaporator in which space between two opposite heat transfer plates 2 serves as a liquid path 3. Sections outside of the heat transfer plates 2 serve as the gas paths 4. To form a real evaporator, it is preferable that the evaporator has a structure in which a plurality of the basic constituent units shown in the drawing are arranged in parallel.

[0080] At the lower end of the liquid path 3, a liquid inlet 5, through which the liquid to be evaporated is supplied to the evaporator 1, is provided, and at the upper end of the liquid path 3, a vapor outlet 6 is provided. The liquid to be evaporated evaporates as flowing from the bottom to the top of the evaporator 1. On the other hand, the heating gas is supplied from gas inlets 7, which are provided at the lower end of the evaporator, and discharged from gas outlets 8, which are provided at the upper end of the evaporator. The evaporator of this embodiment is therefore a same flow direction type evaporator in which the flow directions of the liquid to be evaporated and the heating gas are substantially in a same direction. During operation of the evaporator 1, the inside of the liquid path 3 is composed of a liquid phase region 10, a gas-liquid two phase region 11, and a gas phase region 12 sequentially from the bottom. Size of space S of the liquid path 3 is substantially constant over the entire region of the evaporator 1.

[0081] Next, a description is given of the map of FIG.

14 using FIGS. 12 and 13.

[0082] In Embodiment 8, as shown in FIG. 12, it is assumed that the conditions at the inlet 5 of pure water are mass flow rate m_w (g/s) and temperature T_w (K) and the conditions at the gas inlets 7 are mass flow rate m_g (g/s) and temperature T_g (K). Moreover, the critical heat flux characteristic shown in FIG. 13 varies depending on the space S of the microchannel as previously described, and as the larger the space S is, the higher the critical heat flux is.

[0083] For example, a description is given of the following five patterns of the relation between the quality and the heat flux when the space S is set to S_B . First, when the mass flow rate and temperature at the gas inlet are m_{g2} and T_{g2} , respectively, the heat flux of the high temperature gas and the liquid to be evaporated varies as indicated by a dashed line along with changes in quality and is not more than the critical heat flux of the space S_B in a quality of 0 to 1. In a similar manner, also in cases of (m_{g2}, T_{g1}) and (m_{g1}, T_{g2}) , the heat flux is not more than the critical heat flux of the space S_B . These show that a thin liquid film can be formed to enable an efficient heat exchange.

[0084] On the other hand, in cases of (m_{g2}, T_{g3}) and (m_{g3}, T_{g2}) , as the quality increases, the heat flux of the high temperature gas and the liquid to be evaporated intersects with the critical heat flux characteristic and transits to the dryout region to be considerably reduced. This causes the heat exchange coefficient to be reduced.

[0085] The aforementioned results are put together as FIG. 14 in terms of the relation between the (m_g, T_g) conditions at the inlet of the high temperature gas and the boiling region. This map is in the case where the inlet conditions of the pure water are m_w (g/s) and T_w (K). When it is judged whether the transition to the dryout region is performed and the transition to the dryout region is judged to be performed, the map of FIG. 14 is used to determine a quantitative ΔT_g and Δm_g to make a transition to the wet region. The line separating the dryout region and the wet region in FIG. 14 is created by varying the conditions m_w , (g/s) and T_w (K) in a range of use and plotting the conditions of m_w (g/s) and T_w (K) at which the heat flux characteristic with respect to the quality obtained by experiments or calculations is tangent to the critical heat flux characteristic.

[0086] Next, using FIGS. 18(a) to 18(c), a description is given of a configuration and an operation of systems using the evaporator of this embodiment.

[0087] Each system show in FIGS. 18(a) to 18(c) includes the evaporator 1, a superheater 21, a heating gas inlet 31 of the system, valves 32, 33, and 34 each composed of a three-way valve to switch paths of the heating gas, and a gas outlet 35 of the system. The superheater 21 further heats vapor from the evaporator of the present invention to generate superheated vapor.

[0088] The system of FIG. 18(a) is a system characterized by supplying the heating gas to the superheater 21 and the evaporator 1 in parallel when the mass flow

rate of the heating gas is not less than a prescribed value.

[0089] The system of FIG. 18(b) is a system characterized by supplying the heating gas to the superheater 21 and then to the evaporator 1 when the temperature of the heating gas is not more than a prescribed value.

[0090] The system of FIG. 18(c) is a system characterized by supplying the heating gas to the superheater 21 and the evaporator 1 in parallel and then supplying the heating gas discharged from the superheater 21 to the evaporator 1 when the mass flow rate and temperature of the heating gas are not less than the respective prescribed values.

[0091] Places indicated by thick lines in the drawing show flows of the gas, and a black portion of each three-way valve indicates the direction that the gas flow is stopped. The embodiment is composed of two heat exchangers: one is the above described microchannel-type evaporator 1 mainly used in the wet region; and the other is the superheater 21 to generate superheated vapor. Gas passing through these heat exchangers which are the evaporator 1 and superheater 21 is supplied to a hydrogen generation element such as a not-shown auto thermal reactor (ATR). In a normal state not described below (in the case of the wet region), the gas bypasses the superheater 21 to be supplied. FIGS. 18(a) to 18(c) correspond to FIGS. 15 to 17, respectively, and FIGS. 15 to 17 are simplified and schematically shown. The configuration diagrams shown in FIGS. 18(a) to 18(c) are just examples and do not limit the present invention.

[0092] Next, a description is given of a specific control using FIGS. 14 to 17. FIG. 15 shows a case of a change in a direction A of FIG. 14, or a case where the condition is changed from the condition (m_{g3} , T_{g2}) to the condition (m_{g2} , T_{g2}). FIG. 16 shows a case of a change in a direction B of FIG. 14, or a case where the condition is changed from the condition (m_{g2} , T_{g3}) to the condition (m_{g2} , T_{g2}). FIG. 17 shows a case of a change to a direction C of FIG. 14, or a case where the condition is changed from the condition (m_{g3} , T_{g2}) to the condition (m_{g2} , T_{g1}).

[0093] In the system of FIG. 15, the heating gas supplied at the condition (m_{g3} , T_{g2}) is supplied to the evaporator 1 and the superheater 21 at the condition (m_{g2} , T_{g2}) and the condition (Δm_g , T_{g2}), respectively. The heating gas discharged from the evaporator 1 and the heating gas discharged from the superheater 21 are joined and fed to the ATR. The heating gas discharged from the evaporator 1 may be passed through the superheater 21.

[0094] In the system of FIG. 16, the heating gas supplied at the condition (m_{g2} , T_{g3}) is supplied to the superheater 21 at the condition (m_{g2} , T_{g3}), and the temperature of the heating gas is reduced at the superheater 21 by ΔT_g . The heating gas is then supplied to the evaporator 1 at the condition (m_{g2} , T_{g2}). The heating gas discharged from the evaporator 1 is fed to the ATR. The heating gas discharged from the evaporator 1 may be again passed through the superheater 21.

[0095] In the system of FIG. 17, the heating gas supplied at the condition (m_{g3} , T_{g2}) is supplied to the evap-

orator 1 and the superheater 21 at the conditions (Δm_g , T_{g2}) and ($m_{g3}-\Delta m_g$, T_{g2}), respectively. The heating gas discharged from the superheater 21 is supplied to the evaporator 1 at a temperature ($T_{g2}-\Delta T_g$) and then fed to the ATR. The heating gas discharged from the evaporator 1 may be passed through the superheater 21. In FIGS. 15 to 17, reference numerals 25 to 28 denote a vapor inlet, a superheated vapor outlet, a heating gas inlet, and a heating gas outlet, respectively.

[0096] As described above, in this embodiment, when the mass flow rate of the heating gas is not less than the prescribed value, the heating gas is supplied to the superheater and the microchannel-type evaporator in parallel. When the temperature of the heating gas is not lower than the prescribed value, the heating gas is supplied to the superheater and then supplied to the microchannel-type evaporator. The heat transfer surfaces can be therefore maintained to be wet at narrow spaces with a constant cross section. Accordingly, the evaporator can be reduced in size, and the gas-liquid two phase region can be maintained to have a high heat transfer coefficient. It is therefore possible to realize a compact evaporator with high efficiency.

[0097] Note that the space S is configured to be constant in Embodiment 8 but may be changed like Embodiments 1 to 7.

[0098] The entire contents of Japanese Patent Applications No. 2004-162011 (Filing Date: May 31, 2004) and No. 2002-254611 (Filing Date: September 1, 2004) are herein incorporated by reference.

[0099] Hereinabove, a description is given of the contents of the present invention along the embodiments and examples. However, it is obvious for those skilled in the art that the present invention is not limited to the description about these embodiment and examples and various modifications and improvements can be made.

INDUSTRIAL APPLICABILITY

[0100] In the evaporator of the present invention, a thin liquid film of a liquid to be evaporated is formed on part of heat transfer surfaces coming into contact with a gas-liquid two phase region. The part of the heat transfer surfaces coming into contact with the gas-liquid two phase region can be therefore always maintained to have a high transfer coefficient. Accordingly, the heat exchange efficiency of the evaporator can be increased, and the evaporator can be reduced in size.

Claims

1. A microchannel-type evaporator, comprising:

a path provided substantially vertically, through which a liquid to be evaporated passes, wherein a space size of the path is smaller than diameters of bubbles departing from a heat

- transfer surface of the path, and the space size of the path in a gas-liquid two phase region is a minimum size satisfying that a heat flux is not more than a critical heat flux with respect to a quality.
- 5
2. A microchannel-type evaporator according to claim 1, wherein the space size of the path varies depending on a position in the path in the evaporator. 10
 3. A microchannel-type evaporator according to claim 2, wherein the space size of the path varies along a direction of a flow of the liquid to be evaporated. 15
 4. A microchannel-type evaporator according to claim 2, wherein the space size of the path in a gas phase region gradually decreases in a direction of a flow of the liquid to be evaporated. 20
 5. A microchannel-type evaporator according to claim 3, wherein the flow of the liquid to be evaporated is substantially opposite to a flow of a heating gas, and the space size of the path in the gas-liquid two phase region gradually increases in the direction of the flow of the liquid to be evaporated. 25
 6. A microchannel-type evaporator according to claim 3, wherein the flow direction of the liquid to be evaporated and a flow direction of a heating gas are substantially in a same direction, and a channel space of the path in the gas-liquid two phase region gradually decreases in the direction of the flow of the liquid to be evaporated. 30
 7. A microchannel-type evaporator according to claim 2, wherein the flow of the liquid to be evaporated is substantially orthogonal to a flow of a heating gas, and a channel space of the liquid to be evaporated varies in a direction of a high temperature gas. 35
 8. A microchannel-type evaporator according to claim 7, further comprising: 40

a plurality of turning sections in a heating gas path.
 9. A microchannel-type evaporator according to claim 1, wherein flow directions of the liquid to be evaporated and a heating gas are substantially in a same direction, and 45
- a thin liquid film is formed on the heat transfer surface by controlling a mass flow rate and/or a temperature of a heating gas by use of a map of the mass flow rate and a temperature of the heating gas with respect to a mass flow rate and a temperature of the liquid to be evaporated.
10. A system using a microchannel evaporator, comprising: 50

a microchannel-type evaporator comprising a path provided substantially vertically, through which a liquid to be evaporated passes, wherein a space size of the path is smaller than diameters of bubbles departing from a heat transfer surface of the path, and the space size of the path in a gas-liquid two phase region is a minimum size satisfying that a heat flux is not more than a critical heat flux with respect to a quality; and

a superheater which further heats vapor from the microchannel-type evaporator to generate superheated vapor.
 11. A system using a microchannel evaporator according to claim 10, wherein, in the microchannel-type evaporator, flow directions of the liquid to be evaporated and a heating gas are substantially in a same direction, and when a mass flow rate of the heating gas is not less than a prescribed value, the heating gas is supplied to the superheater and the microchannel-type evaporator in parallel. 55
 12. A system using a microchannel evaporator according to claim 10, wherein, in the microchannel-type evaporator, flow directions of the liquid to be evaporated and a heating gas are substantially in a same direction, and when a temperature of the heating gas is not less than a prescribed value, the heating gas is supplied to the superheater and then supplied to the microchannel-type evaporator.
 13. A system using a microchannel evaporator according to claim 10, wherein, in the microchannel-type evaporator, flow directions of the liquid to be evaporated and a heating gas are substantially in a same direction, and when a mass flow rate and a temperature of the heating gas are not less than respective prescribed values, the heating gas is supplied to the superheater and the microchannel-type evaporator in parallel, and the heating gas discharged from the superheater is further supplied to the microchannel-type evaporator.

FIG. 1

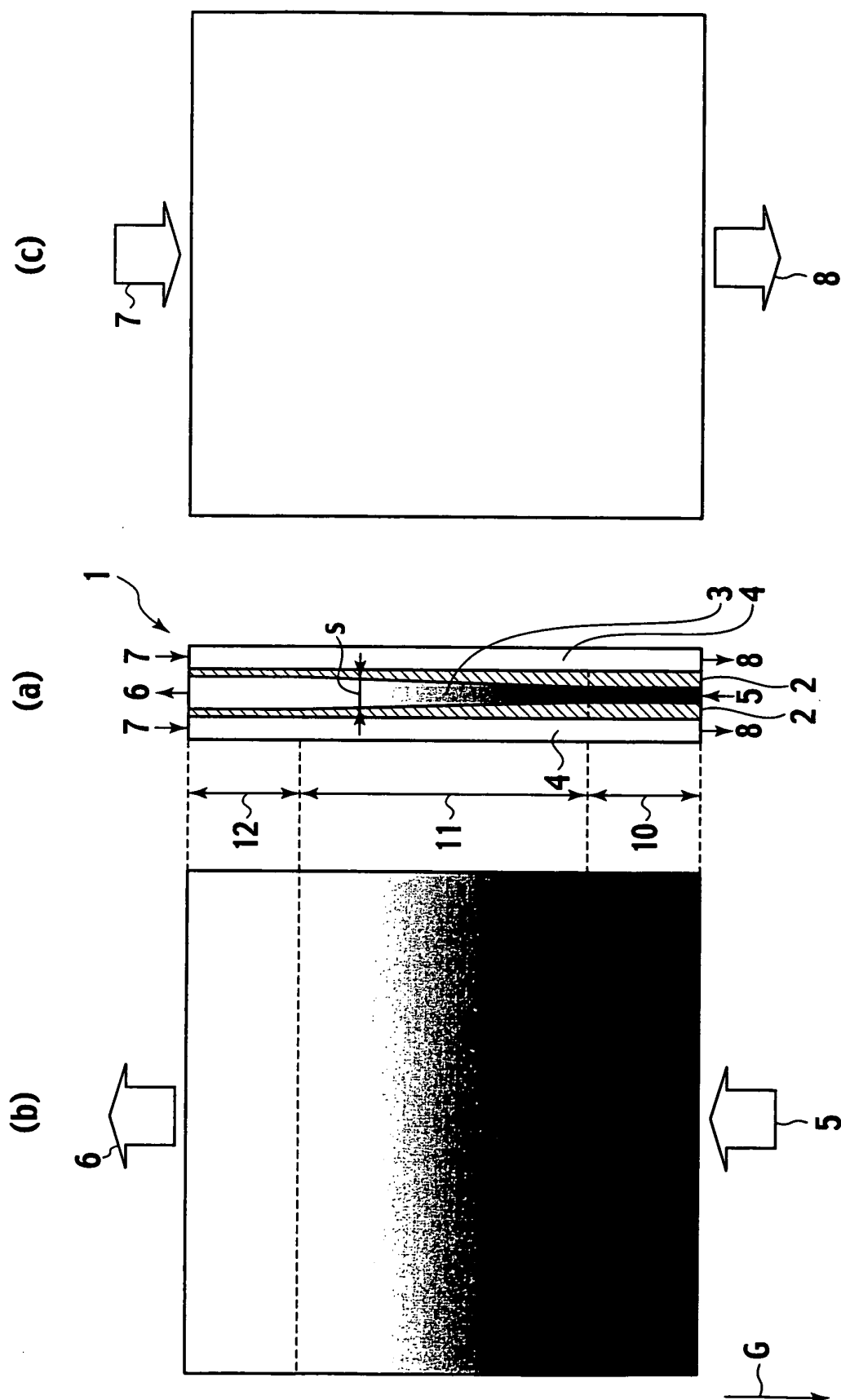


FIG. 2

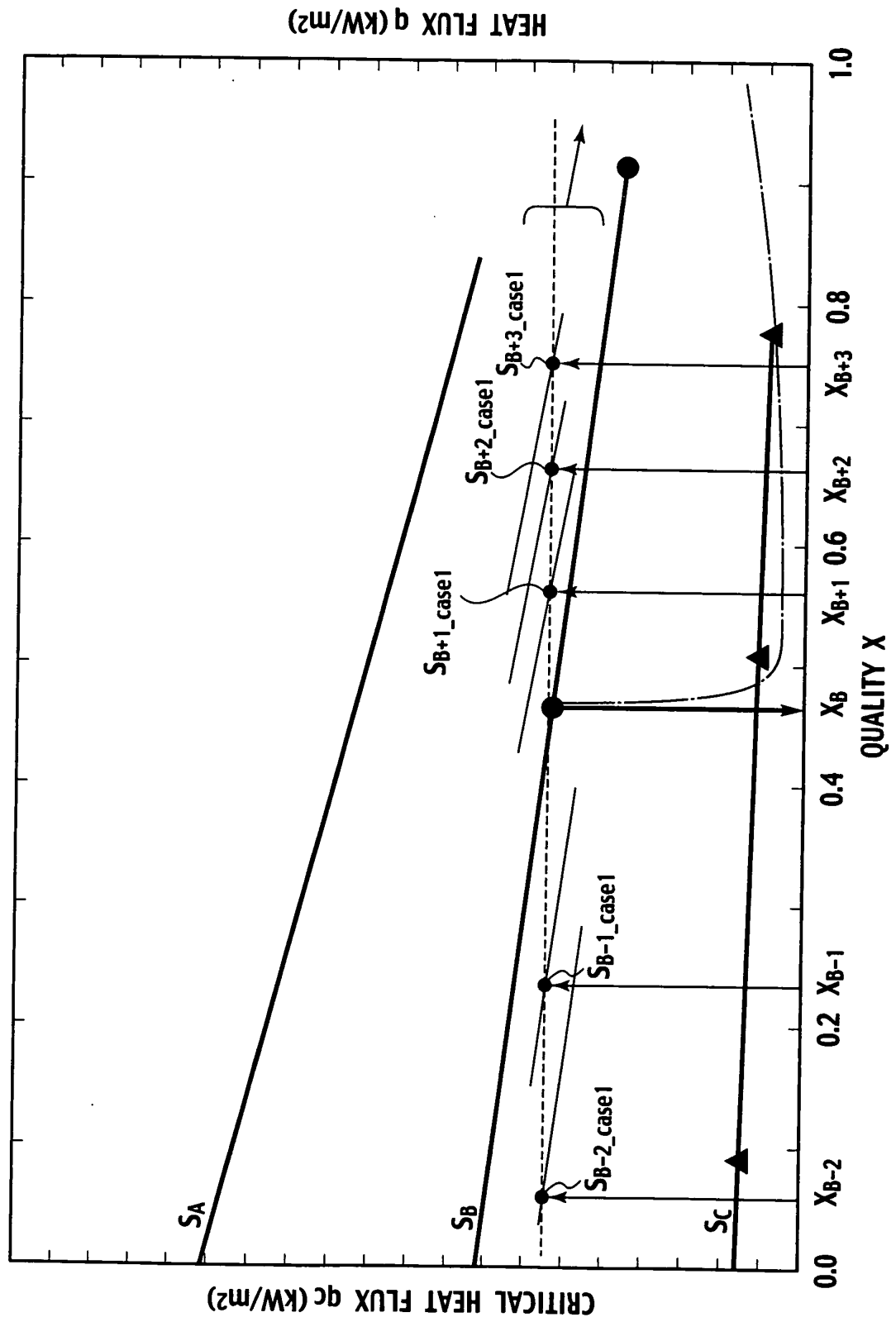
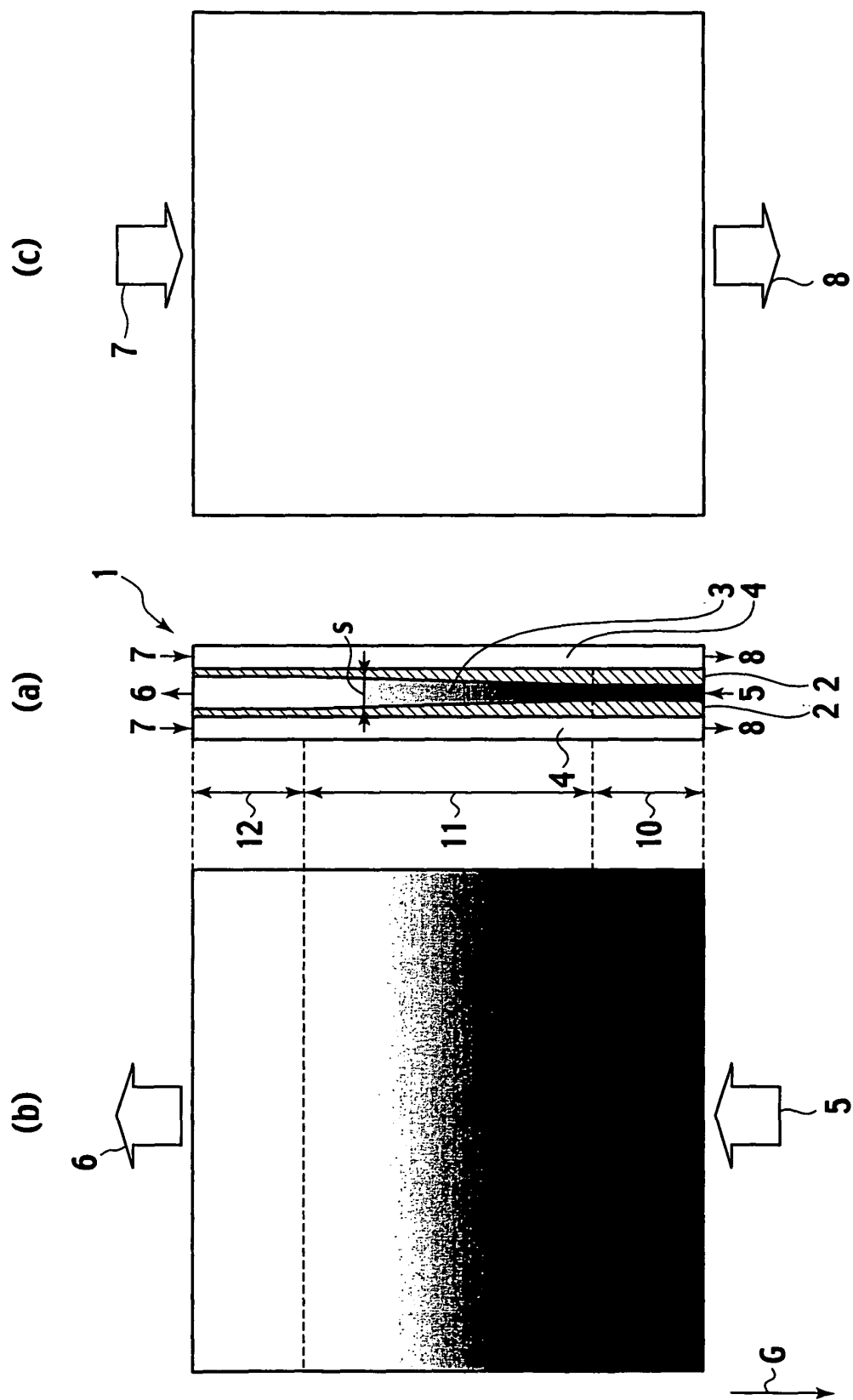


FIG. 3



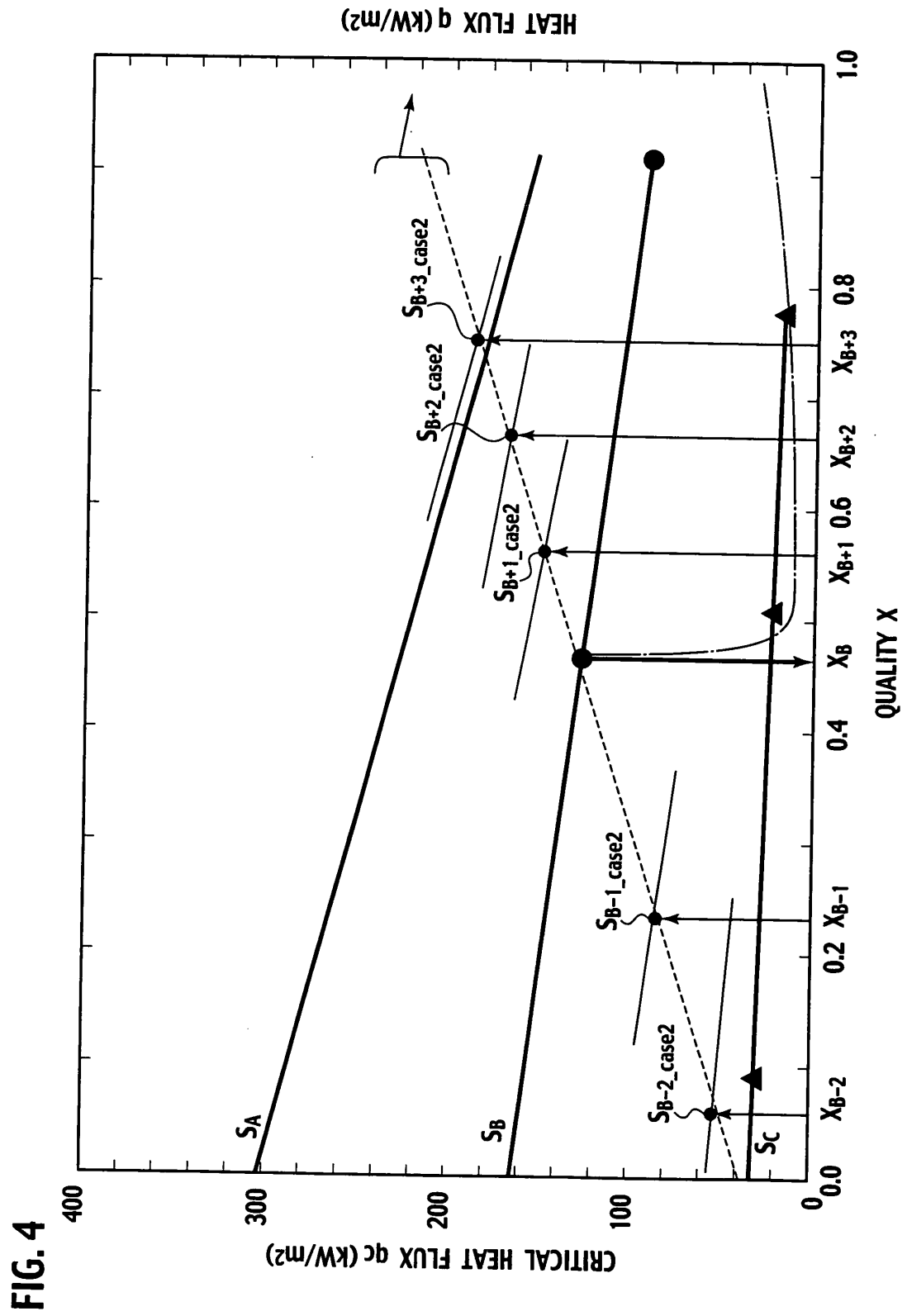


FIG. 5

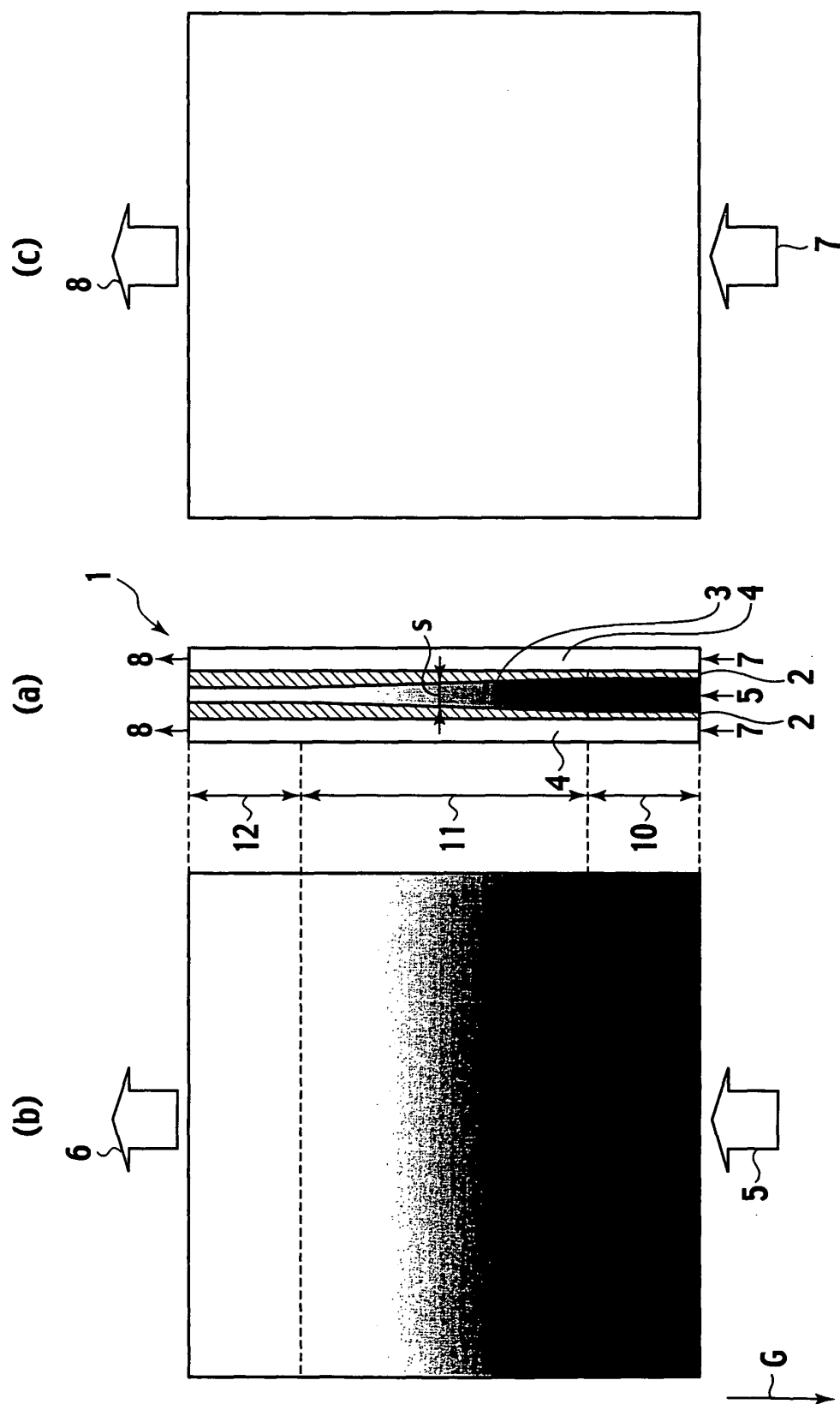
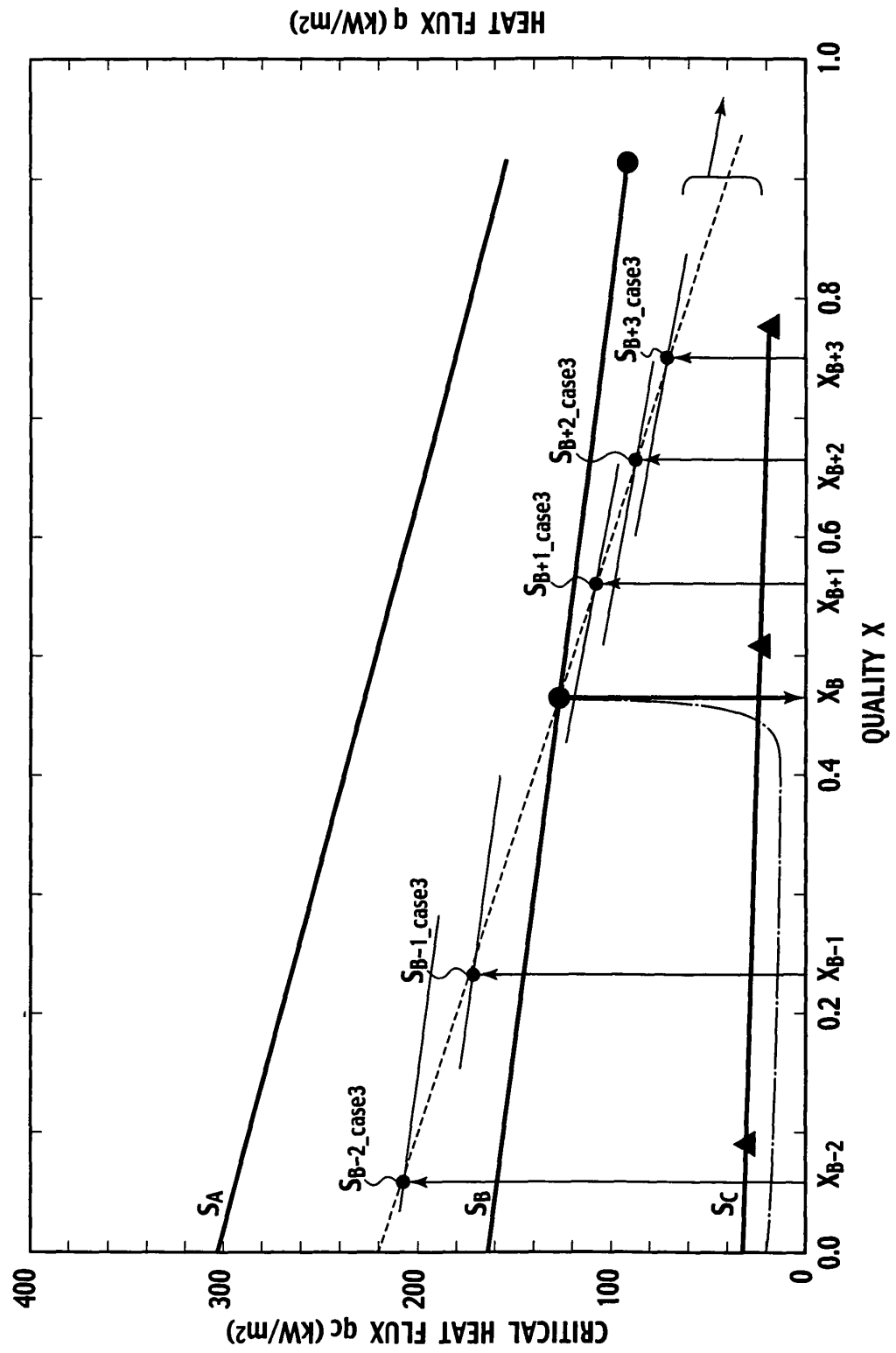
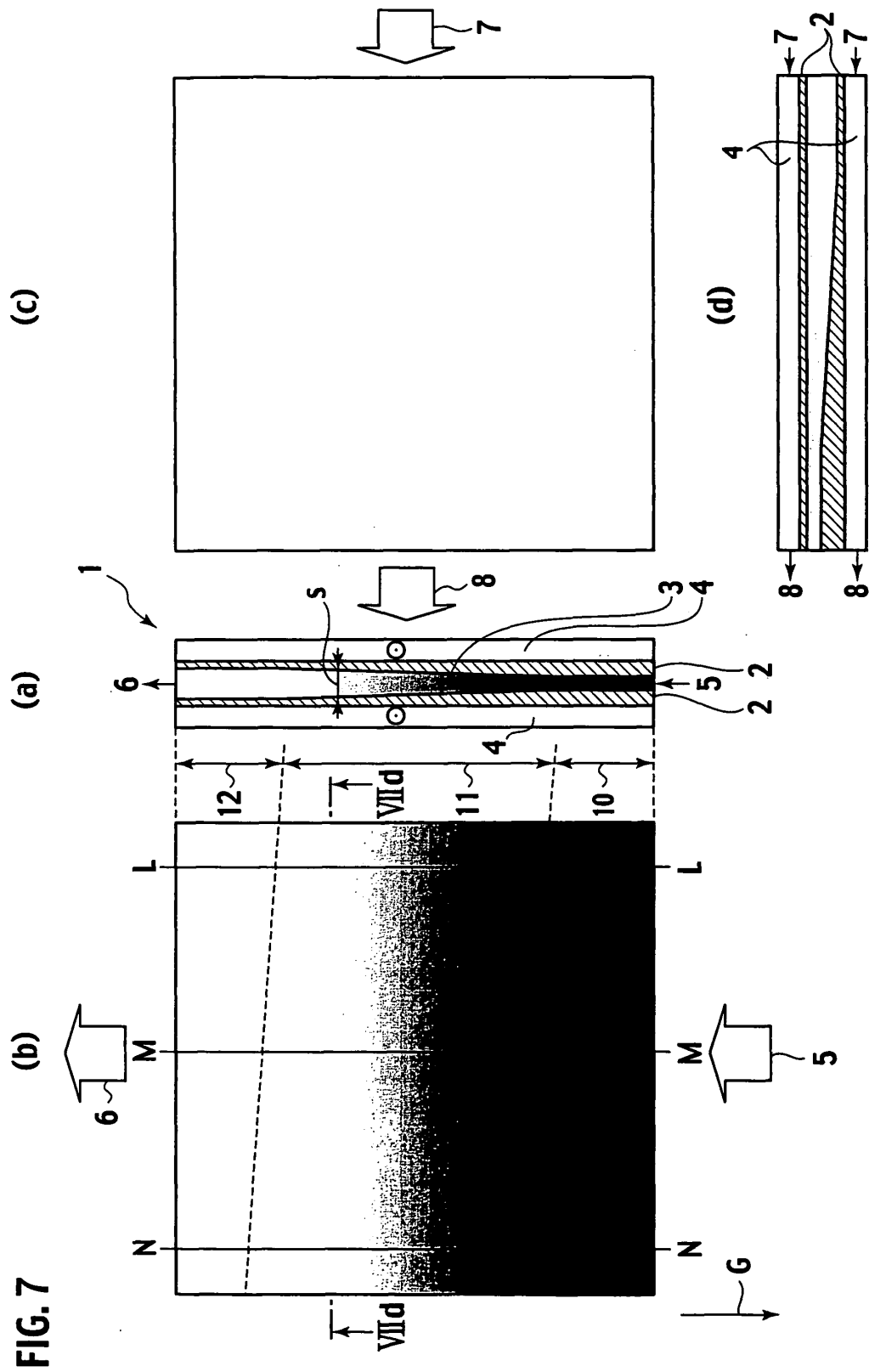


FIG. 6





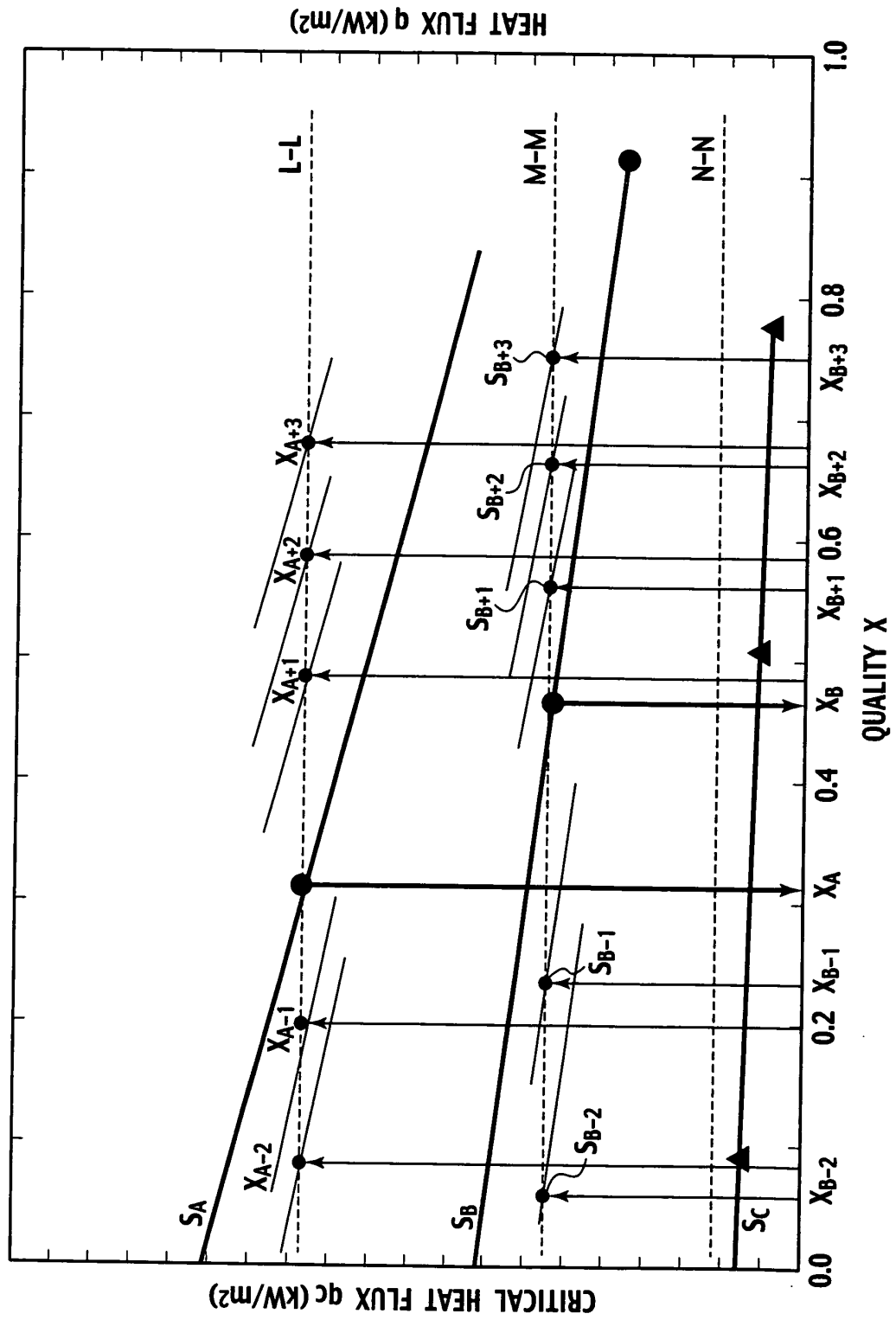


FIG. 9

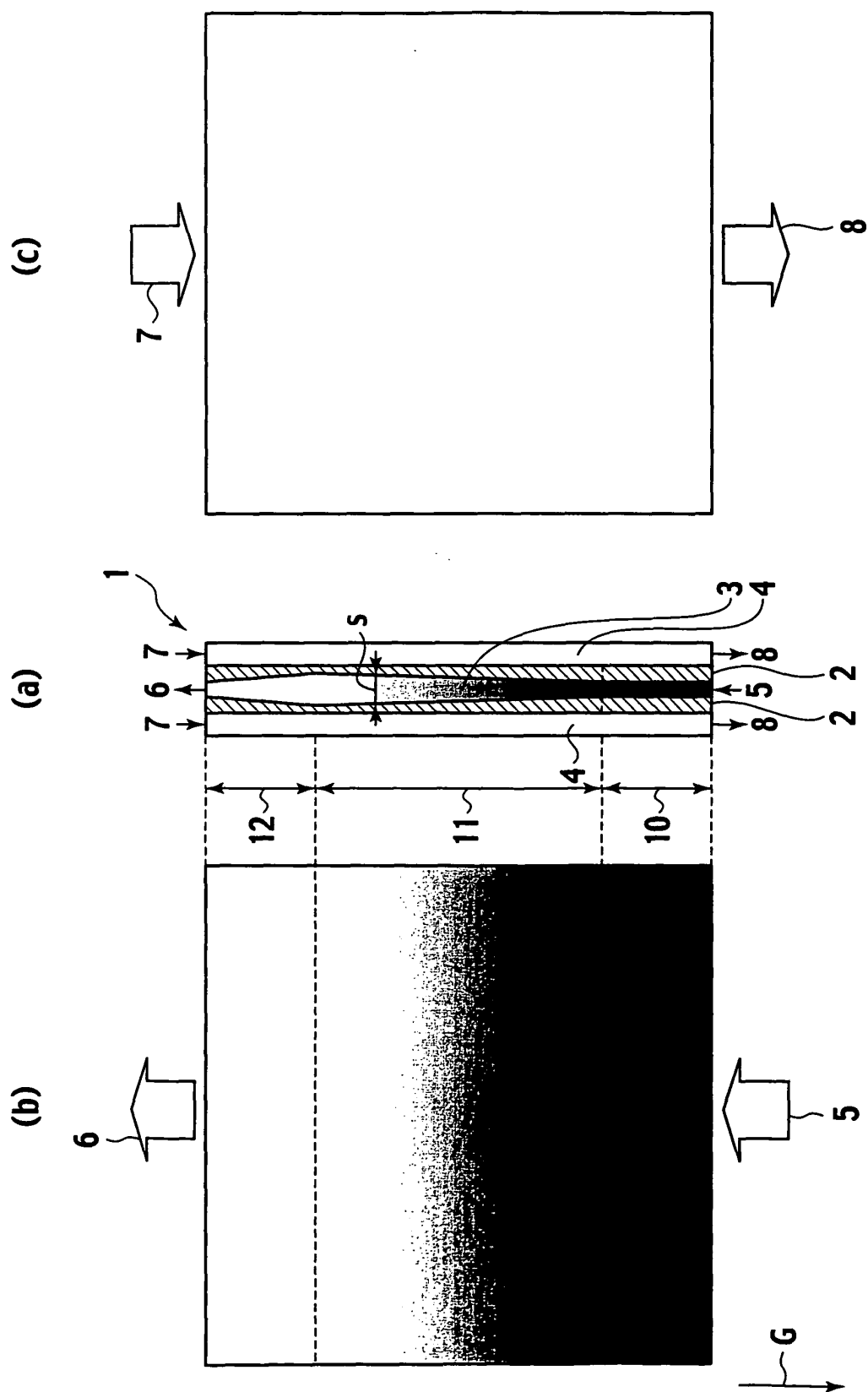


FIG. 10

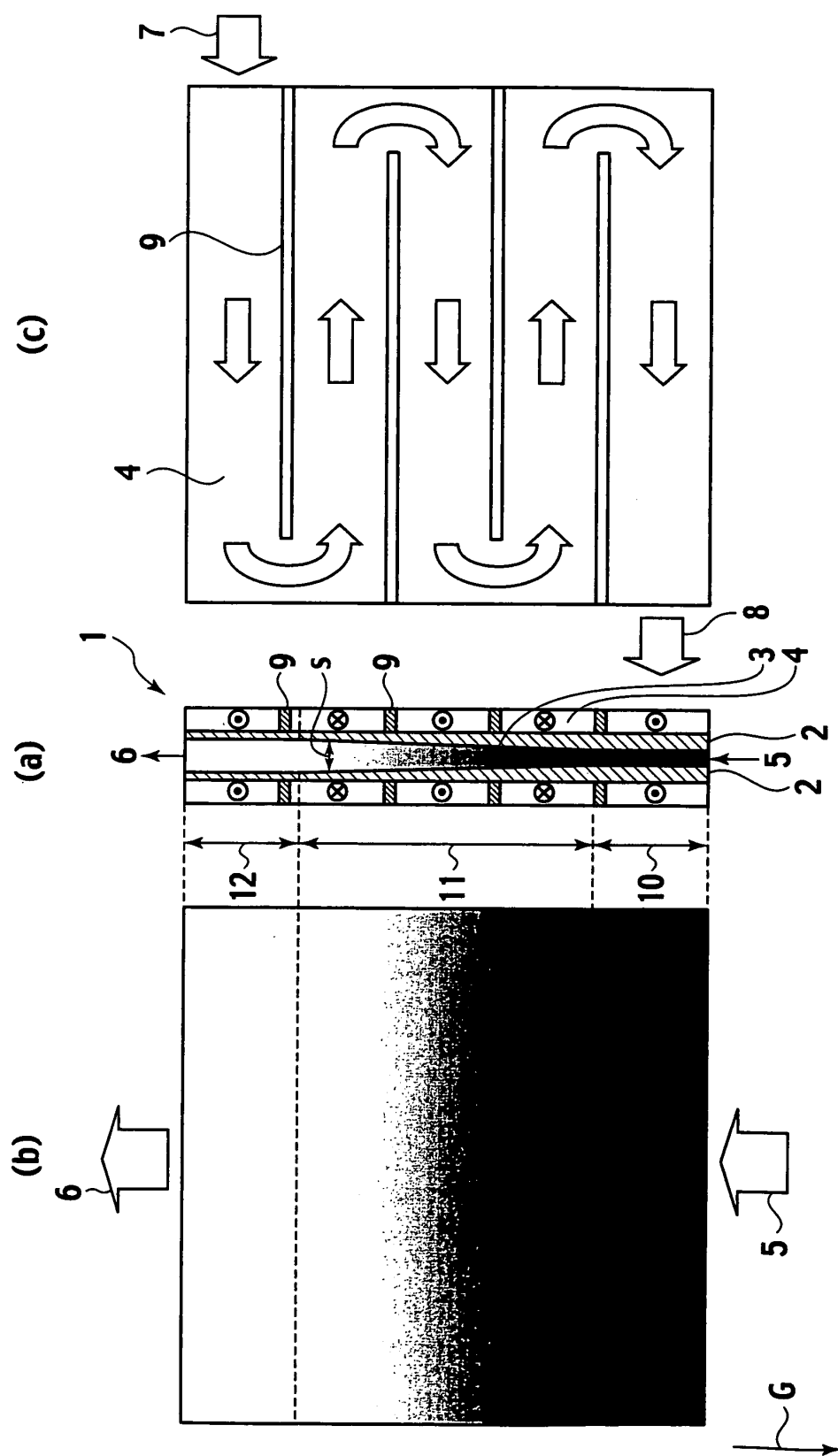


FIG. 11

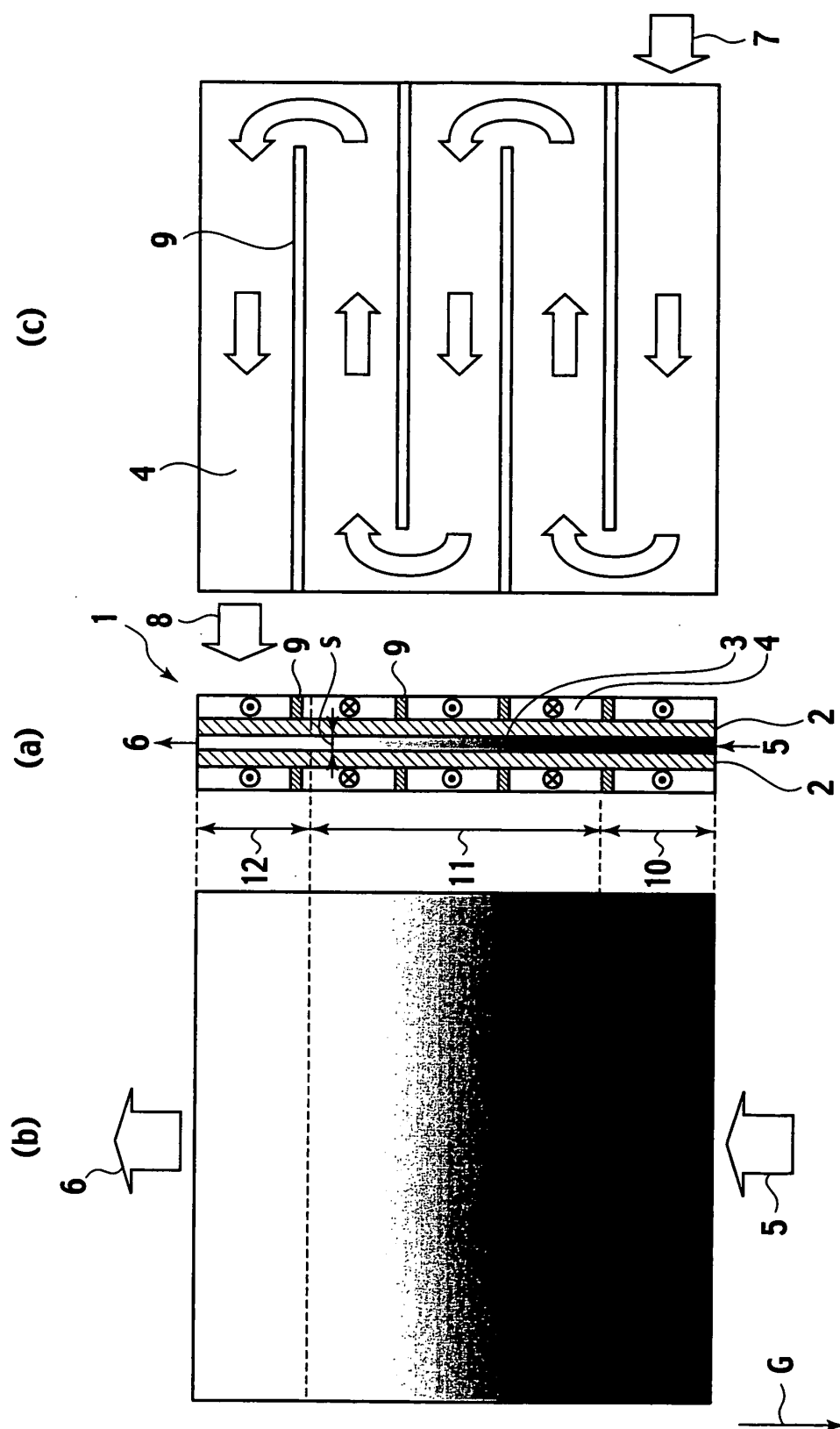
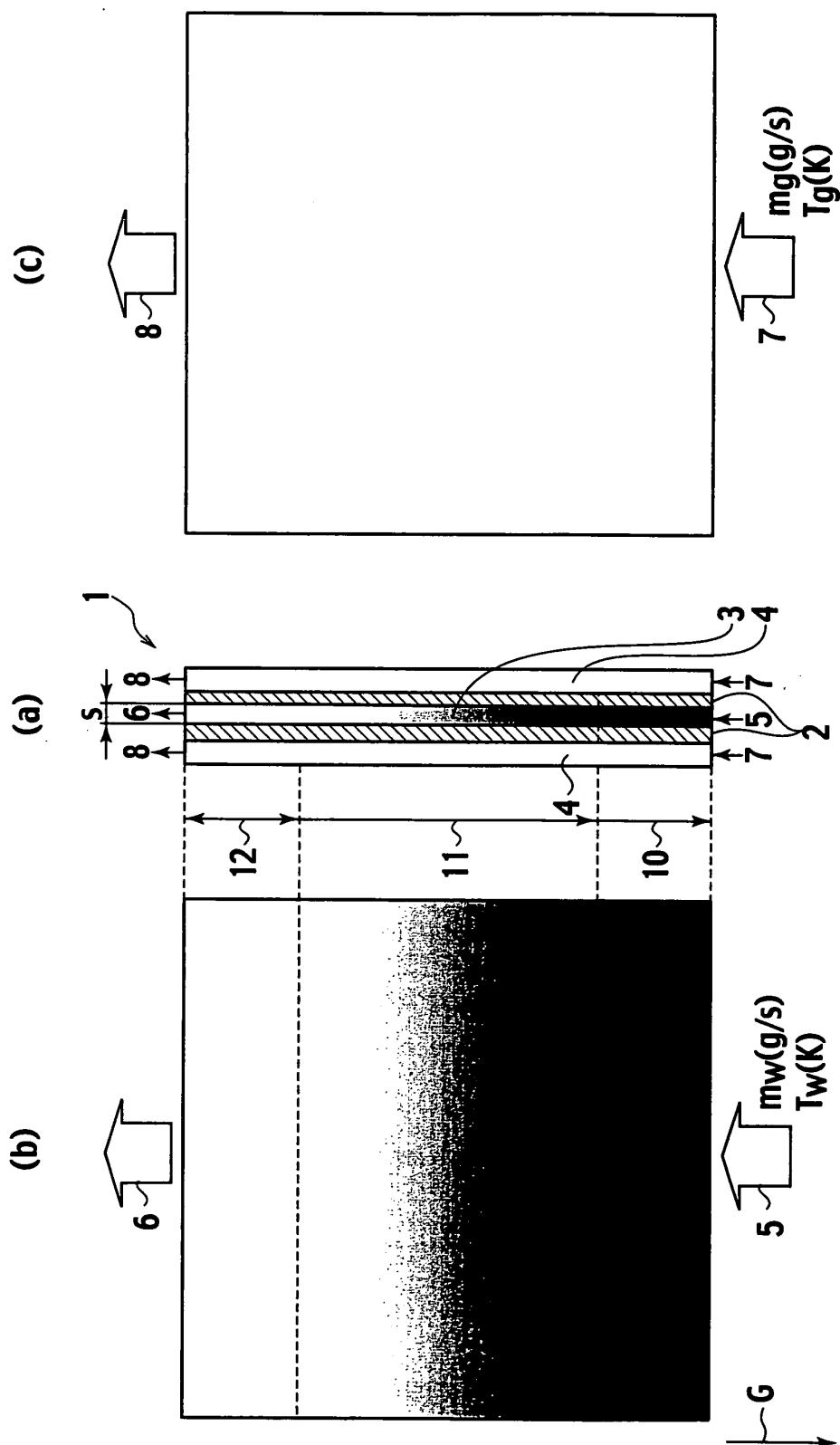


FIG. 12



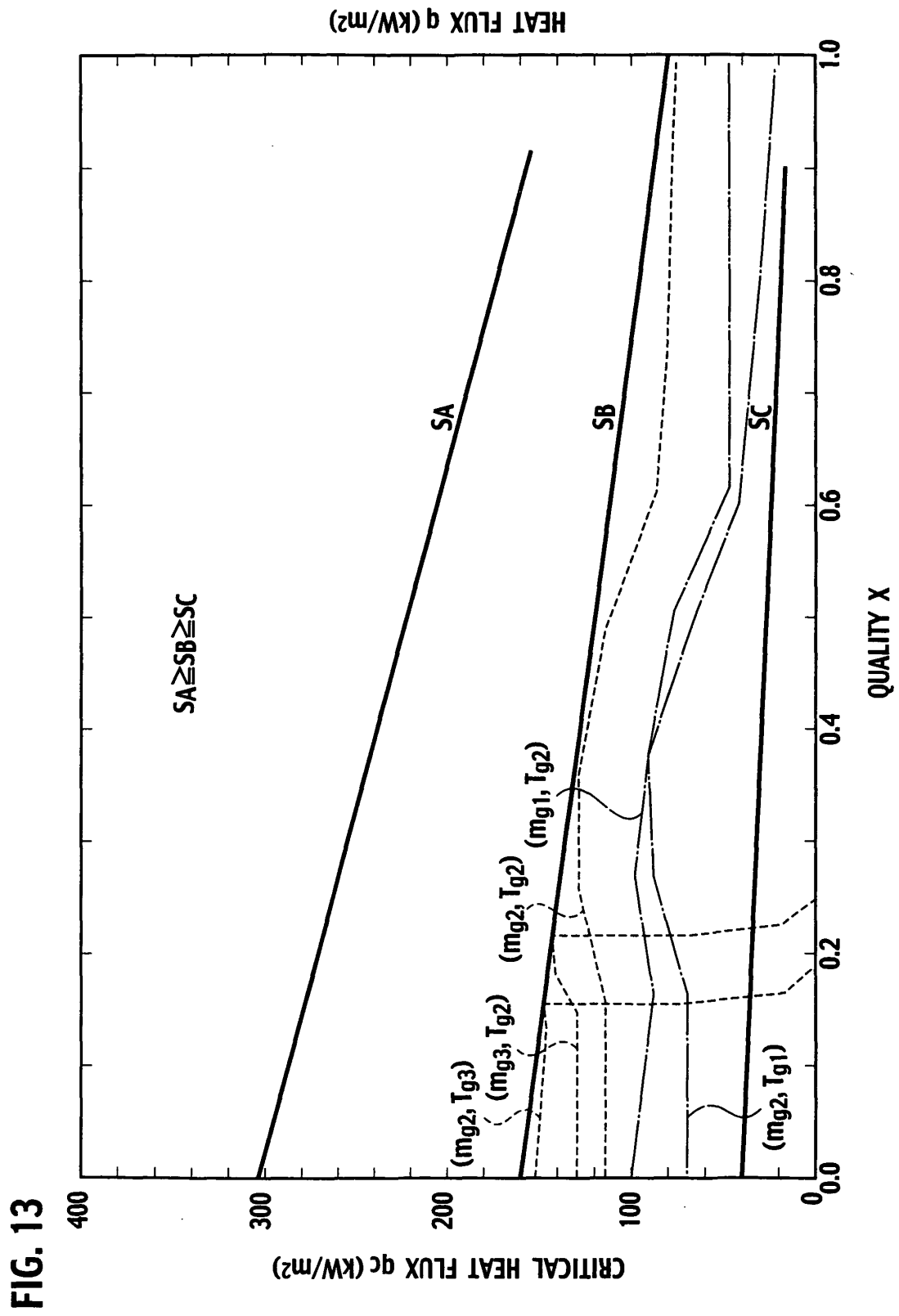
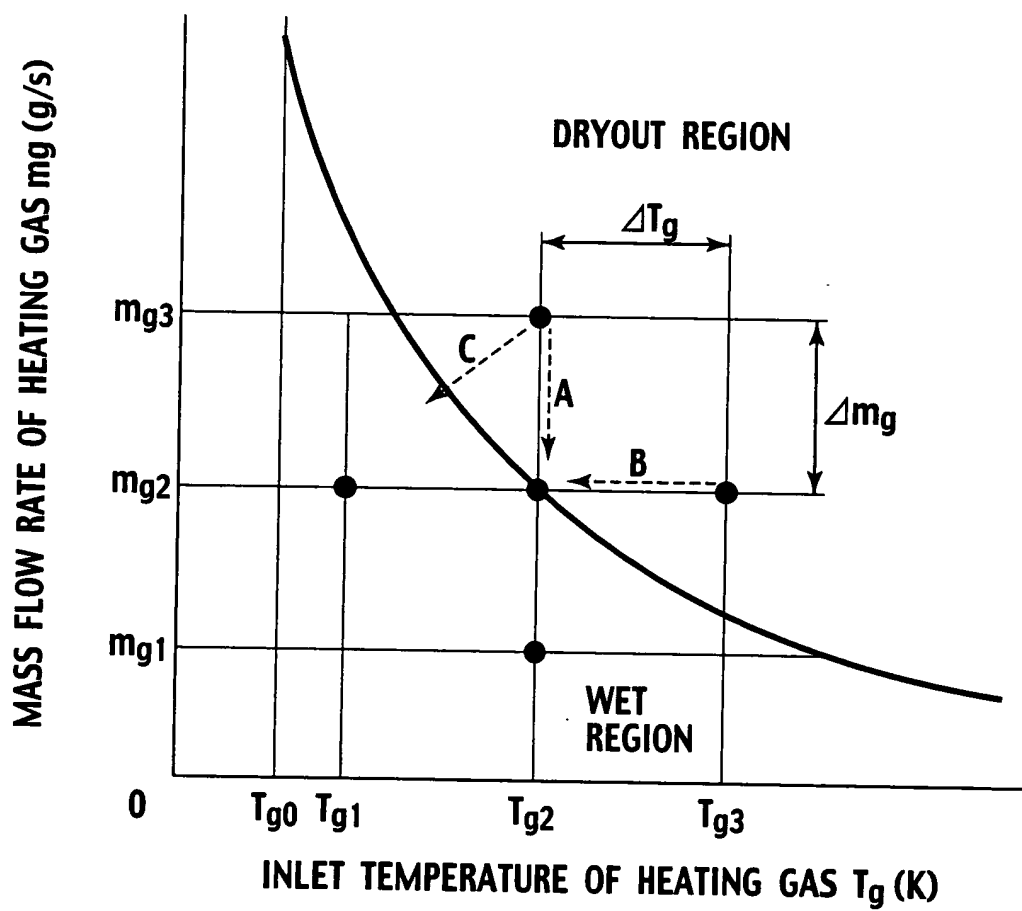
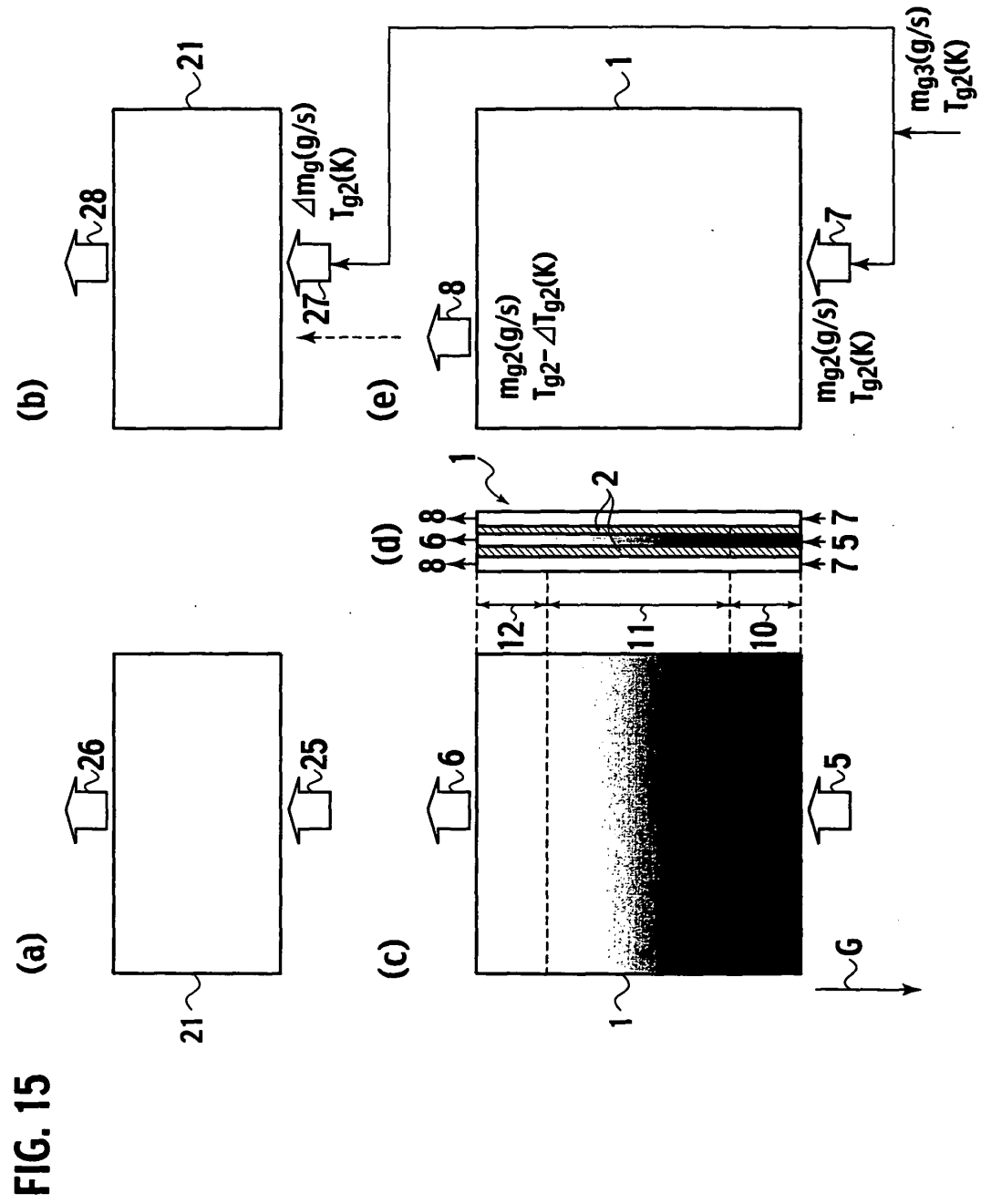


FIG. 14

SPACE SIZE : SB
 FLOW RATE OF WATER : $m_w(\text{g/s})$
 TEMPERATURE OF WATER : $T_w(\text{K})$



T_{g0} : SATURATION TEMPERATURE



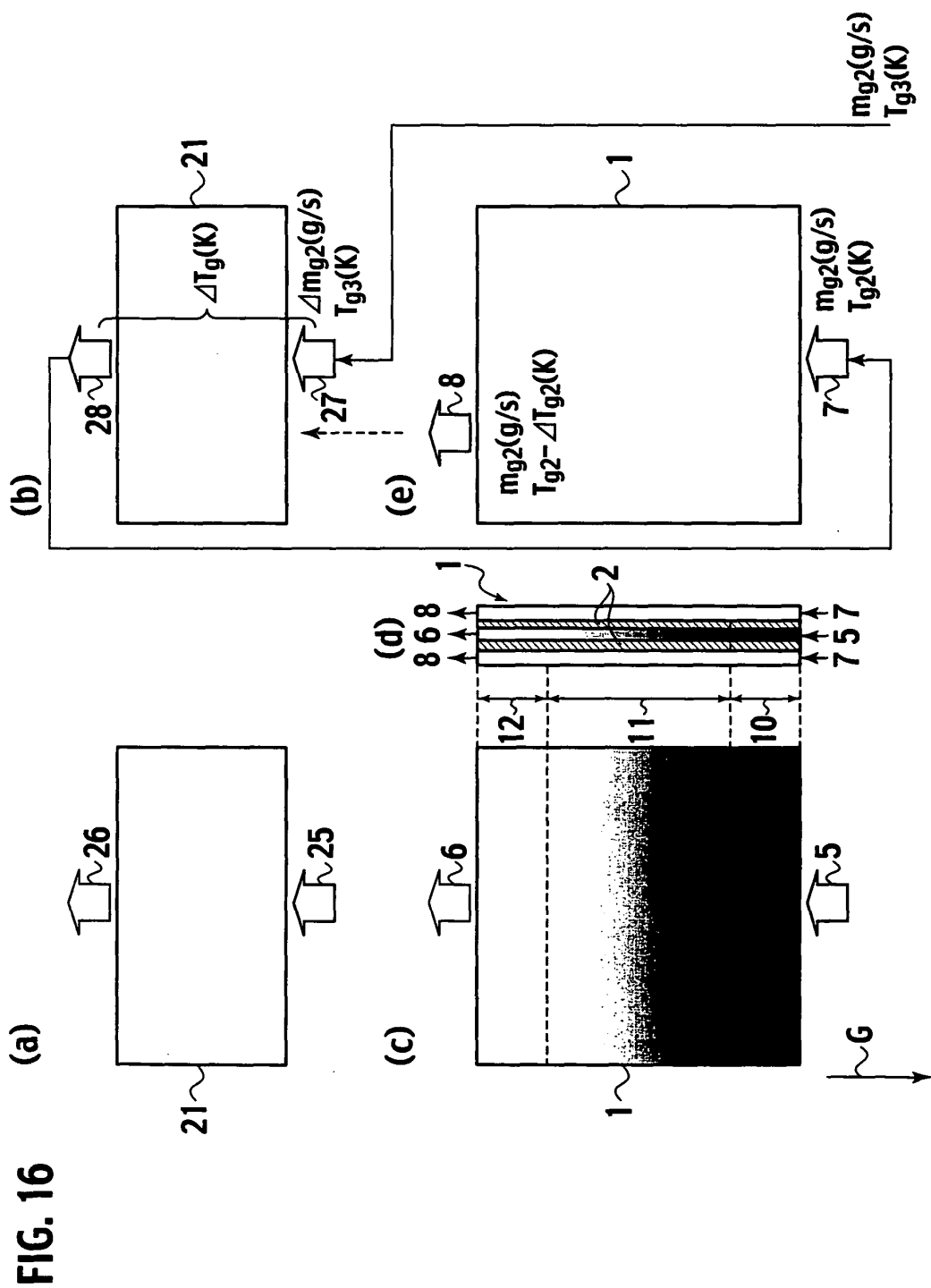


FIG. 17

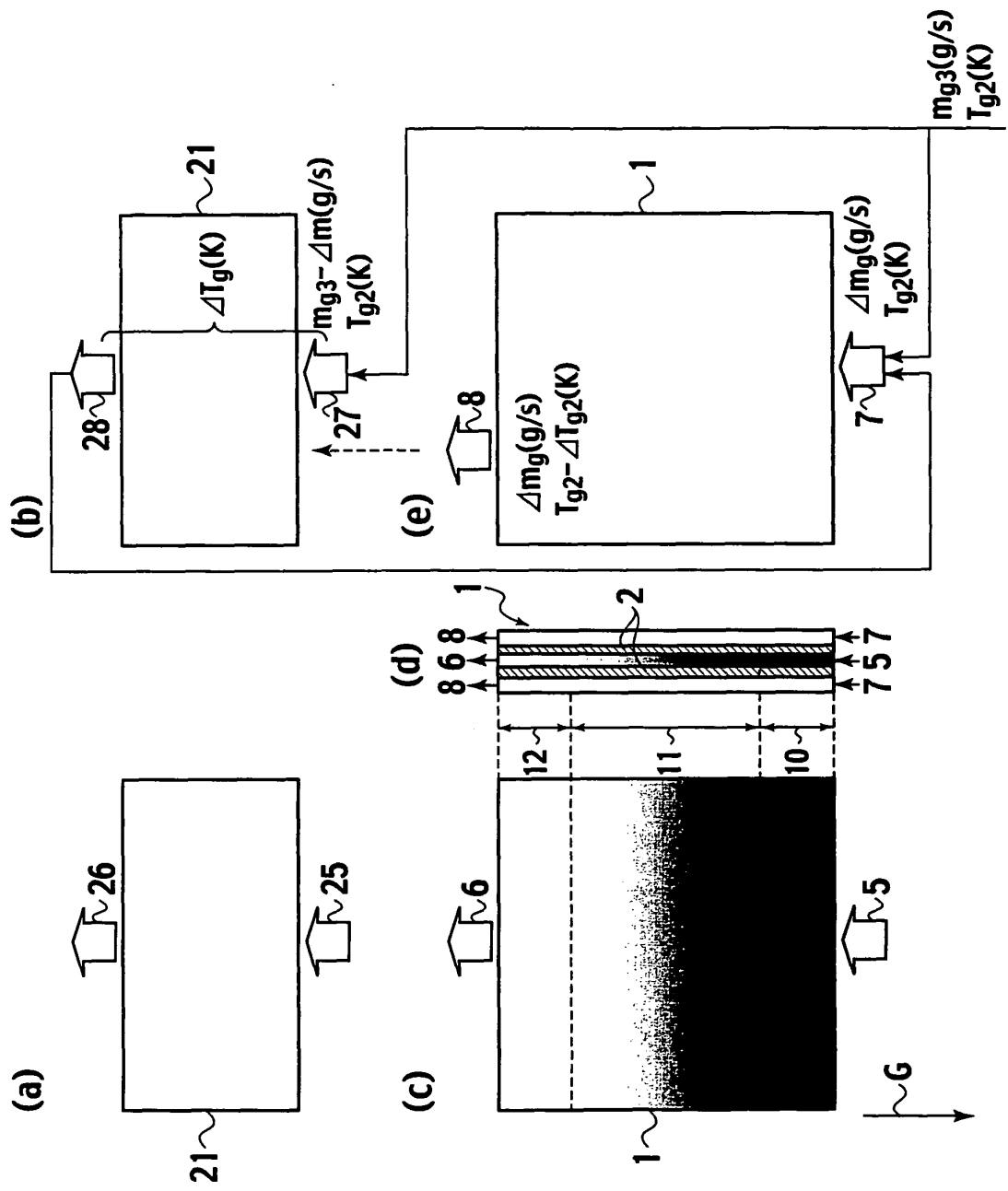


FIG. 18

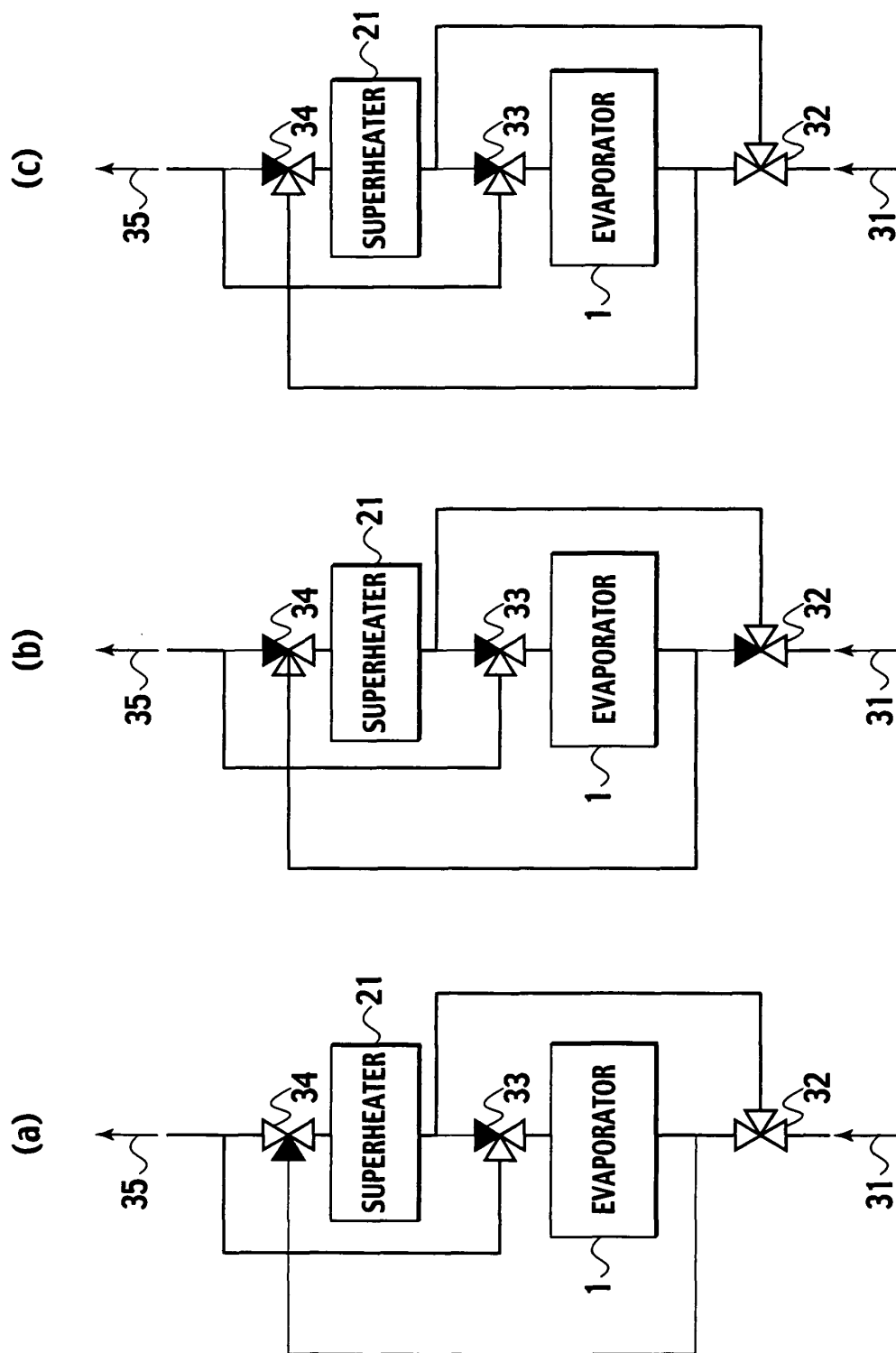


FIG. 19

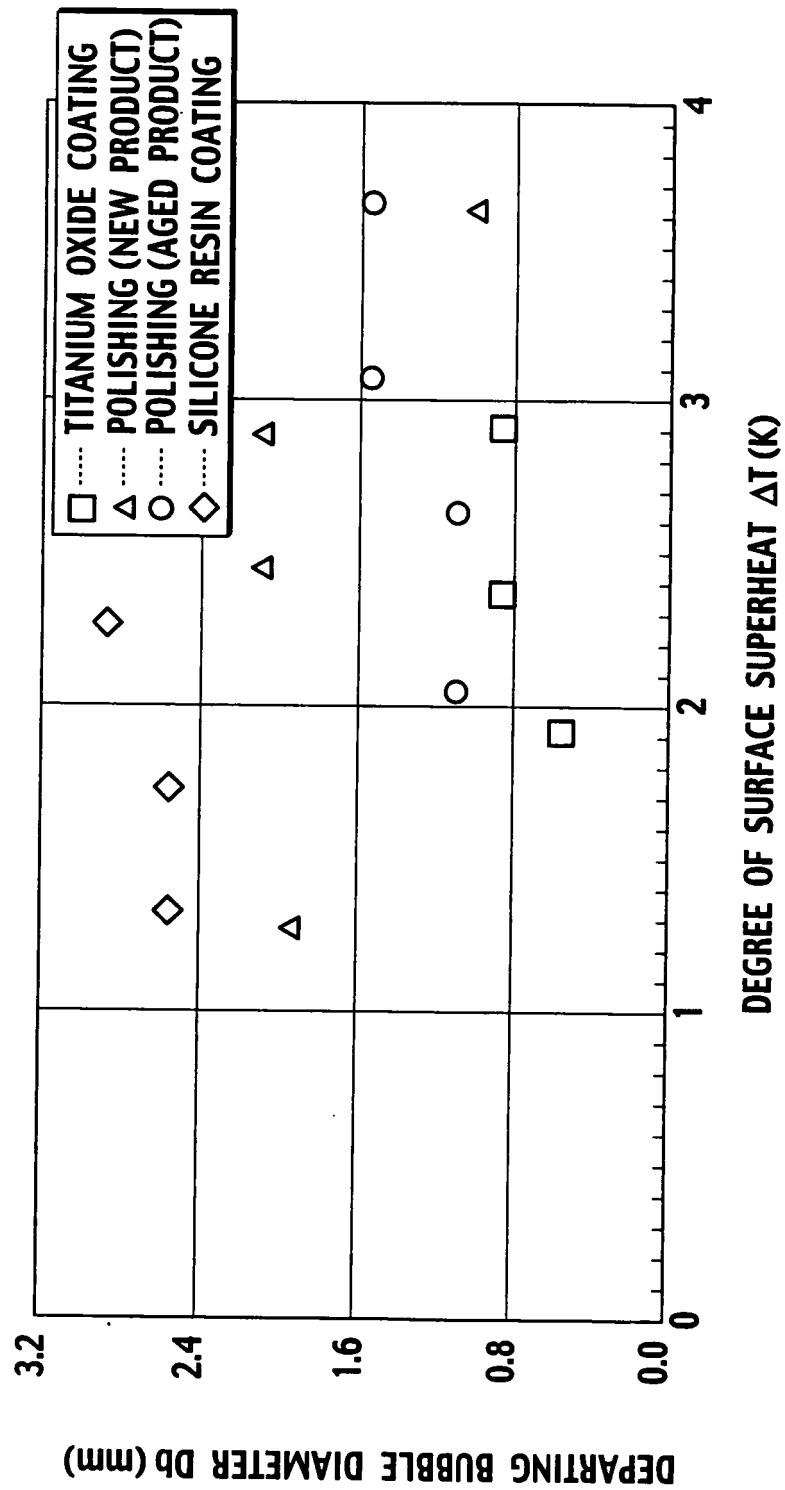


FIG. 20A

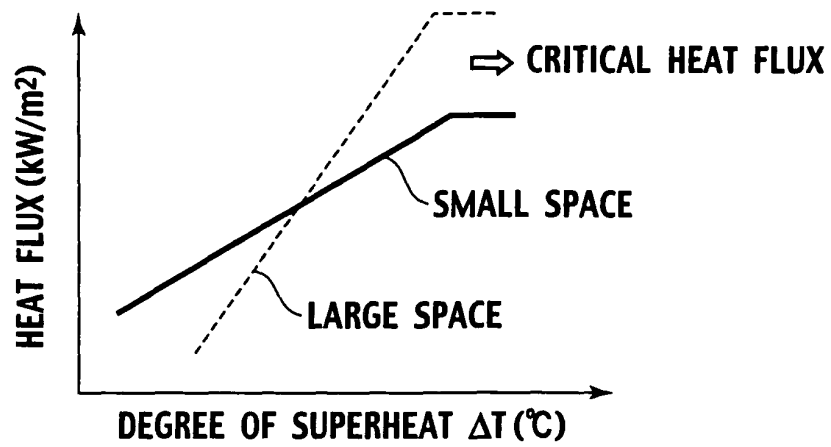


FIG. 20B

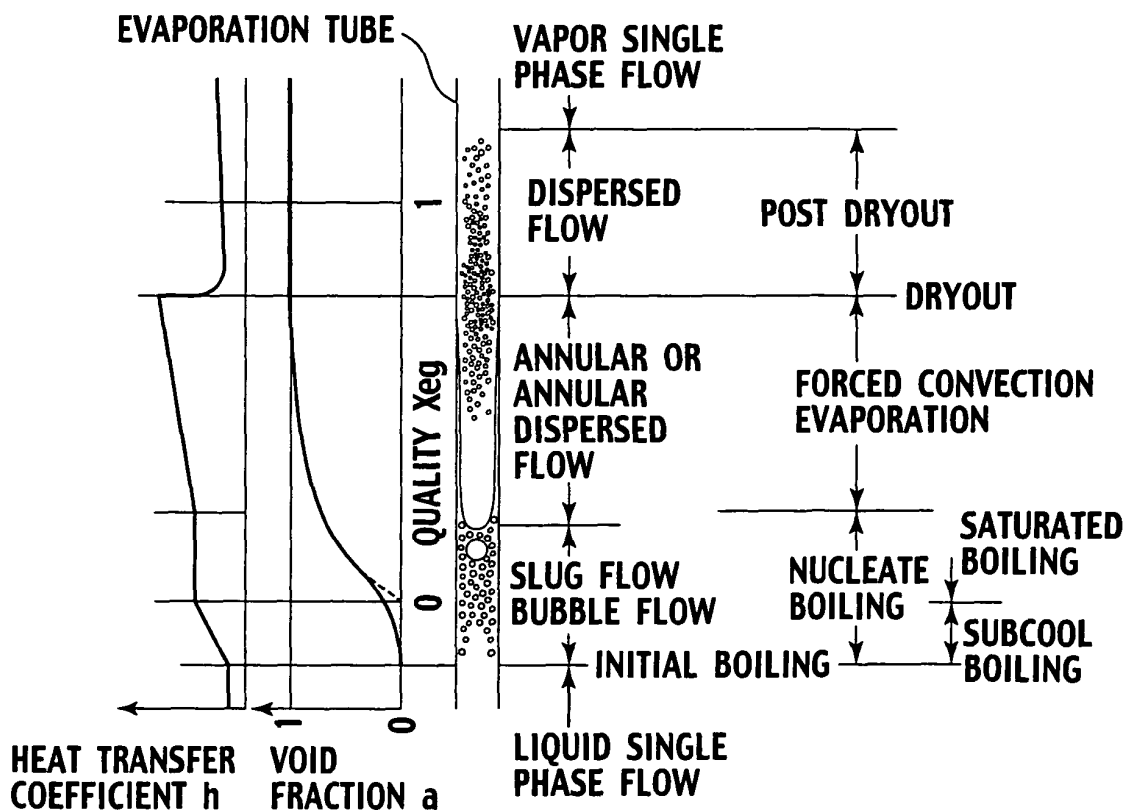


FIG. 20C

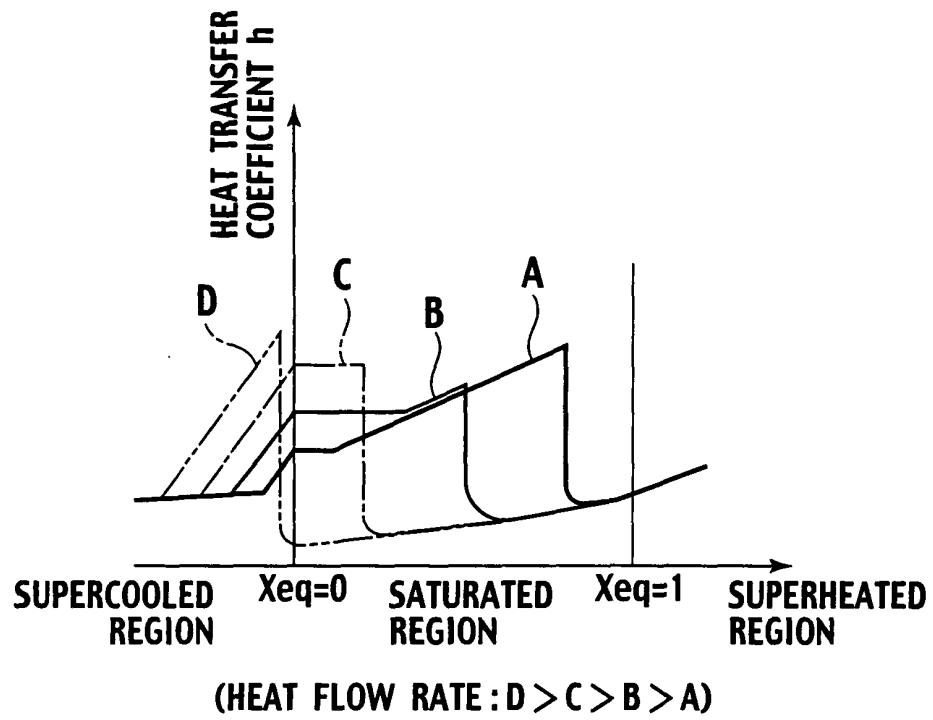


FIG. 21

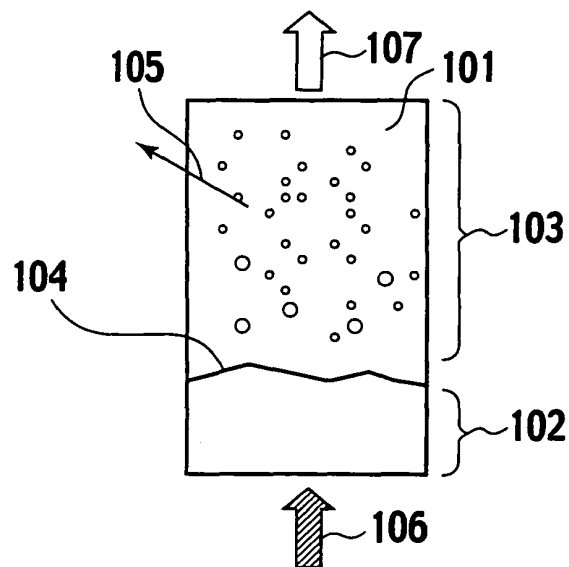


FIG. 22

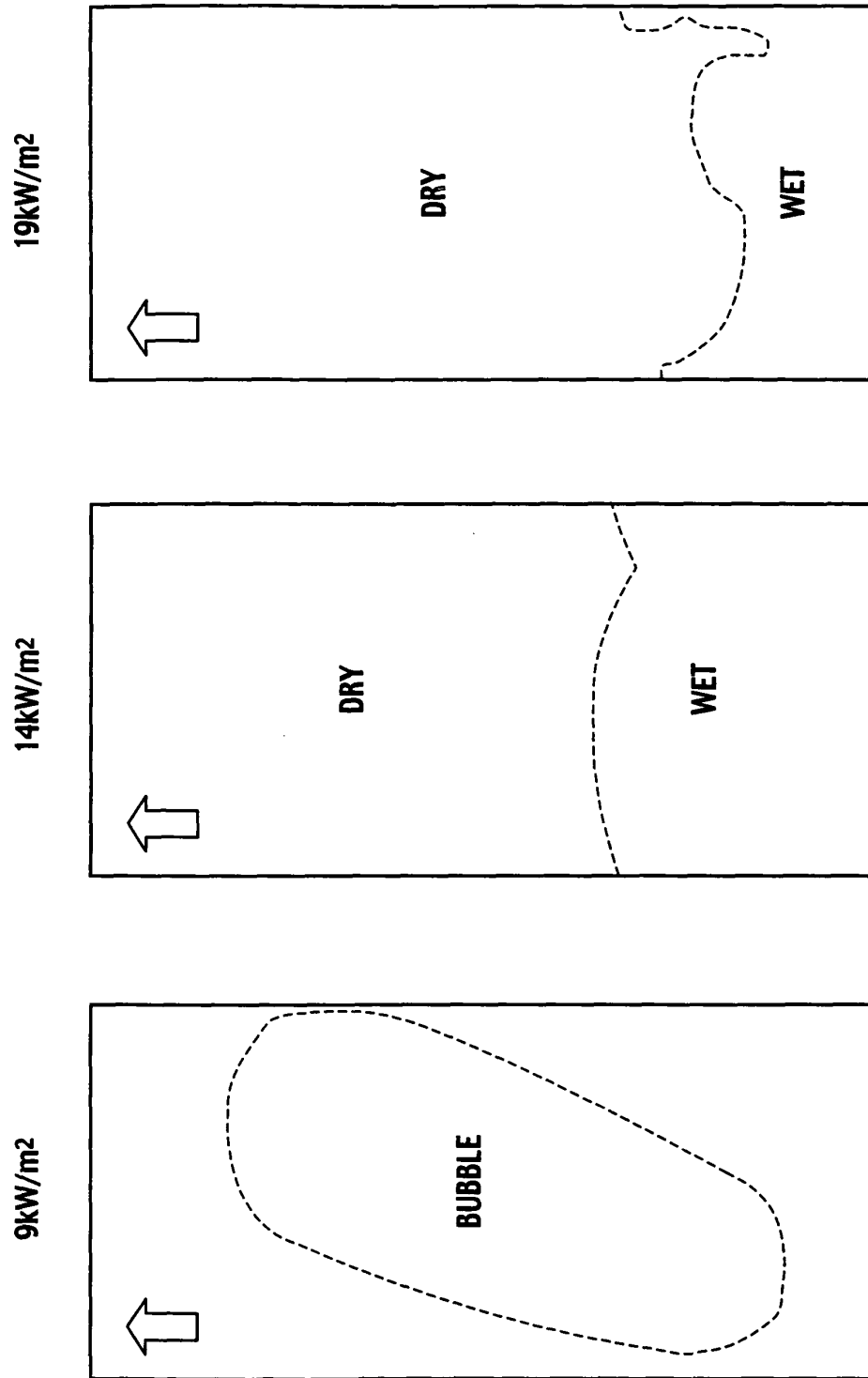


FIG. 23A

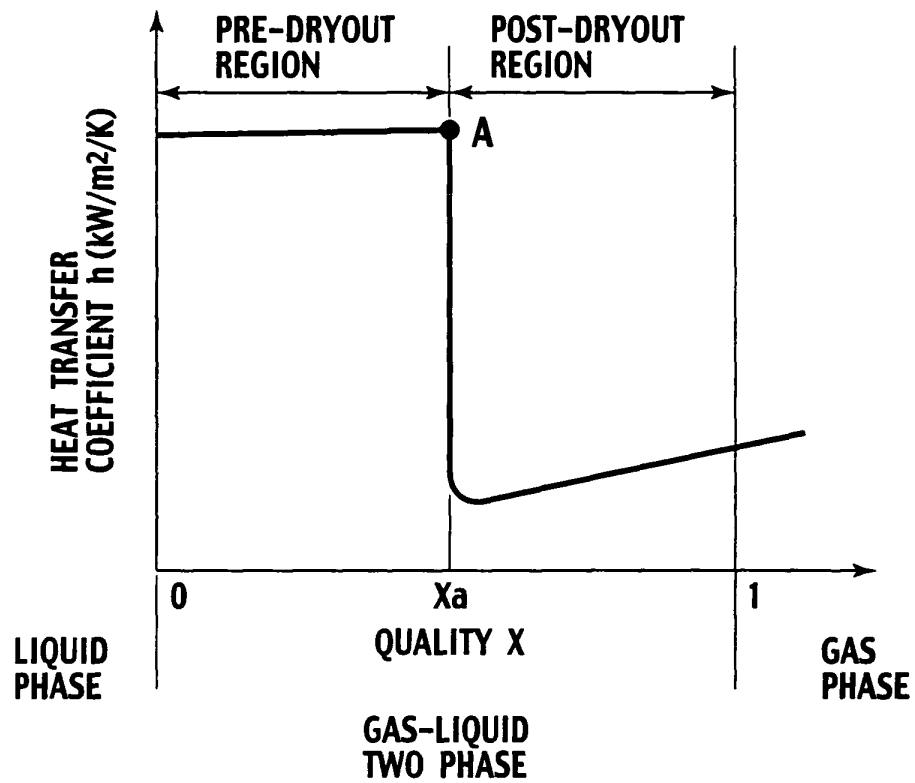
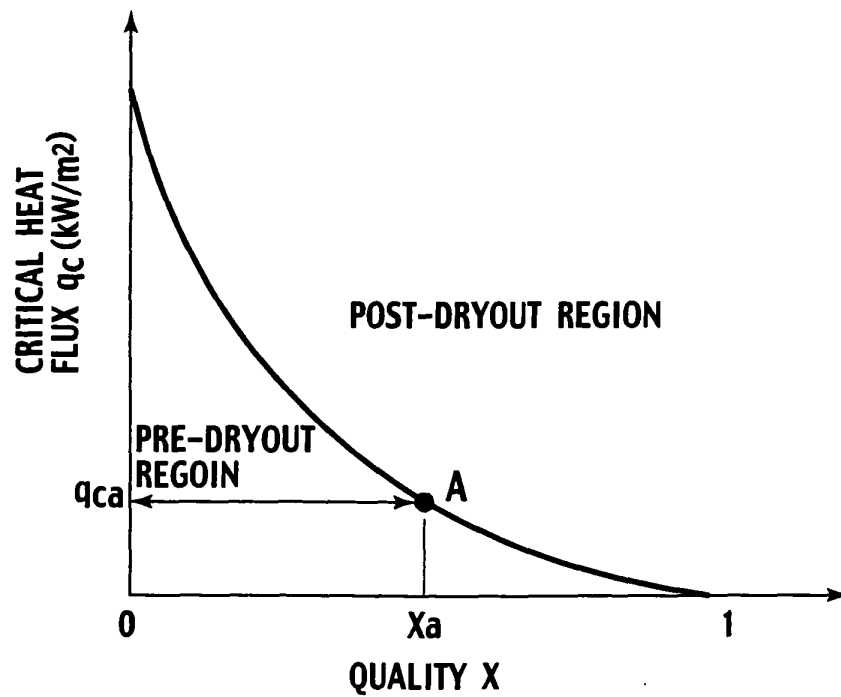


FIG. 23B



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2005/007428

A. CLASSIFICATION OF SUBJECT MATTER Int.Cl. ⁷ F28F13/08		
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. ⁷ F28F13/00		
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.
X	JP 2003-156201 A (Komatsu Ltd.),	1, 2, 7
Y	30 May, 2003 (30.05.03),	10
A	Full text; Figs. 1 to 13 (Family: none)	3-6, 8, 9, 11-13
Y	JP 2003-343278 A (Ishikawajima-Harima Heavy Industries Co., Ltd.), 03 December, 2003 (03.12.03), Par. No. [0024]; Fig. 1 (Family: none)	10
☐ 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 05 August, 2005 (05.08.05)		Date of mailing of the international search report 16 August, 2005 (16.08.05)
Name and mailing address of the ISA/ Japanese Patent Office		Authorized officer
Facsimile No.		Telephone No.

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REFERENCES CITED IN THE DESCRIPTION

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- JP 2004162011 A [0098]
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