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(54) HEAT EXCHANGER AND AIR CONDITIONER

(57) A heat exchanger includes a main heat exchanger and a sub-heat exchanger connected to the main heat exchanger. The main heat exchanger includes a plurality of main heat transfer tubes extending in an up-down direction, each of the plurality of main heat transfer tubes having a flow passage inside which refrigerant flows, a first main header into which one end portion of each of the main heat transfer tubes is inserted, main fins provided to the main heat transfer tubes and helping heat exchange between air and refrigerant flowing inside the main heat transfer tubes, and a second main header into which the other end portion of each of the main heat transfer tubes is inserted, the second main header being opposite to the first main header. The sub-heat exchanger includes a plurality of sub-heat transfer tubes extending in an up-down direction, each of the plurality of sub-heat transfer tubes having a flow passage inside which refrigerant flows, sub-fins provided to the sub-heat transfer tubes and helping heat exchange between air and refrigerant flowing inside the sub-heat transfer tubes, a first sub-header into which one end portion of each of the sub-heat transfer tubes is inserted, and a second sub-header into which the other end portion of each of the sub-heat transfer tubes is inserted, the second sub-header being opposite to the first sub-header. The heat exchanger satisfies Expression (1) below, where the number of the main heat transfer tubes is represented as N_1, and the number of the sub-heat transfer tubes is represented as N_2. The heat exchanger satisfies Expressions (2) and (3) below, where a cross-sectional area of the flow passage of each of the main heat transfer tubes is represented as Ta_1, a cross-sectional area of the flow passage of each of the sub-heat transfer tubes is represented as Ta_2, a cross-sectional area of the first main header per each of the main heat transfer tubes is represented as Ha_1, and a cross-sectional area of the first sub-header per each of the sub-heat transfer tubes is represented as Ha_2. The heat exchanger satisfies Expressions (4) and (5) below, where a sum total of cross-sectional areas of the flow passages of the main heat transfer tubes is represented as AT_1, a sum total of cross-sectional areas of the flow passages of the sub-heat transfer tubes is represented as AT_2, a flow rate [kG/h] of all refrigerant flowing through the main heat exchanger is represented as Gr_1, a flow rate [kG/h] of all refrigerant flowing through the sub-heat exchanger is represented as Gr_2, a gravitational acceleration [m/s^2] is represented as G, an equivalent diameter [m] of a cross-section of the flow passage of each of the main heat transfer tubes is represented as D_1, an equivalent diameter [m] of a cross-section of the flow passage of each of the sub-heat transfer tubes is represented as D_2, a density [kG/m^3] of liquid refrigerant flowing in the main heat transfer tubes is represented as ρL_1,

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a density [kG/m^3] of liquid refrigerant flowing in the sub-heat transfer tubes is represented as ρL_2, a density [kG/m^3] of gas refrigerant flowing in the main heat transfer tubes is represented as ρG_1, a density [kG/m^3] of gas refrigerant flowing in the sub-heat transfer tubes is represented as ρG_2, a quality [-] of refrigerant flowing in the main heat exchanger is represented as X_1, and a quality [-] of refrigerant flowing in the sub-heat exchanger is represented as X_2.

$$0.03 < Ta_1/Ha_1 < 0.3 \cdots (1) \quad (1)$$

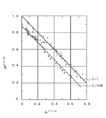
$$0.03 < Ta_2/Ha_2 < 0.3 \cdots (2) \quad (2)$$

$$0.1 < N_2/(N_1 + N_2) < 0.4 \cdots (3) \quad (3)$$

$$AT_1 < Gr_1/(G \times D_1(\rho L_1 - \rho G_1))^{(1/2)} \times (X_1^{(1/2)} \times \rho G_1^{(-1/4)} + (1 - X_1)^{(1/2)} \times \rho L_1^{(-1/4)})^2 \cdots (4) \quad (4)$$

$$AT_2 < Gr_2/(G \times D_2(\rho L_2 - \rho G_2))^{(1/2)} \times (X_2^{(1/2)} \times \rho G_2^{(-1/4)} + (1 - X_2)^{(1/2)} \times \rho L_2^{(-1/4)})^2 \cdots (5) \quad (5)$$

FIG. 7



Description

Technical Field

[0001] The present disclosure relates to a heat exchanger including heat transfer tubes, and also relates to an air-conditioning apparatus including the heat exchanger.

Background Art

[0002] Some heat exchangers has been known that includes a plurality of heat transfer tubes, and a pair of headers into which opposite end portions of the heat transfer tubes are inserted. Patent Literature 1 discloses a heat exchanger in which a value of the ratio, obtained by dividing the cross-sectional area of flow passages of a single heat transfer tube by the cross-sectional area of the header per the single heat transfer tube, ranges from 3% to 30%. Patent Literature 1 applies this ratio to the heat exchanger to improve its heat exchange performance.

Citation List

Patent Literature

[0003] Patent Literature 1: Japanese Patent No. 4686062

Summary of Invention

Technical Problem

[0004] However, as disclosed in Patent Literature 1, in the heat exchanger with a relatively large number of heat transfer tubes, when a low air conditioning load is applied to the heat exchanger, and thus a refrigerant flow rate is relatively low, then refrigerant in a two-phase gas-liquid state may not be able to flow upward inside the heat transfer tubes, but may flow backward. In Patent Literature 1, there is a possibility that this back flow may cause pressure loss inside the heat transfer tubes, and consequently heat exchange performance may be degraded.

[0005] The present disclosure has been achieved to solve the above problems, and it is an object of the present disclosure to provide a heat exchanger and an air-conditioning apparatus including the heat exchanger, in which the heat exchanger reduces the likelihood of the occurrence of pressure loss of refrigerant in heat transfer tubes to improve heat exchange performance.

Solution to Problem

[0006] A heat exchanger according to an embodiment of the present disclosure includes a main heat exchanger and a sub-heat exchanger connected to the main heat exchanger. The main heat exchanger includes a plurality of main heat transfer tubes extending in an up-down direction, each of the plurality of main heat transfer tubes having a flow passage inside which refrigerant flows, a first main header into which one end portion of each of the plurality of main heat transfer tubes is inserted, main fins provided to the plurality of main heat transfer tubes and helping heat exchange between air and refrigerant flowing inside the plurality of main heat transfer tubes, and a second main header into which an other end portion of each of the plurality of main heat transfer tubes is inserted, the second main header being opposite to the first main header. The sub-heat exchanger includes a plurality of sub-heat transfer tubes extending in an up-down direction, each of the plurality of sub-heat transfer tubes having a flow passage inside which refrigerant flows, sub-fins provided to the plurality of sub-heat transfer tubes and helping heat exchange between air and refrigerant flowing inside the plurality of sub-heat transfer tubes, a first sub-header into which one end portion of each of the plurality of sub-heat transfer tubes is inserted, and a second sub-header into which an other end portion of each of the plurality of sub-heat transfer tubes is inserted, the second sub-header being opposite to the first sub-header. The heat exchanger satisfies Expression (1) below, where the number of the plurality of main heat transfer tubes is represented as N_1, and the number of the plurality of sub-heat transfer tubes is represented as N_2. The heat exchanger satisfies Expressions (2) and (3) below, where a cross-sectional area of the flow passage of each of the plurality of main heat transfer tubes is represented as Ta_1, a cross-sectional area of the flow passage of each of the plurality of sub-heat transfer tubes is represented as Ta_2, a cross-sectional area of the first main header per each of the plurality of main heat transfer tubes is represented as Ha_1, and a cross-sectional area of the first sub-header per each of the plurality of sub-heat transfer tubes is represented as Ha_2. The heat exchanger satisfies Expressions (4) and (5) below, where a sum total of cross-sectional areas of the flow passages of the plurality of main heat transfer tubes is represented as AT_1, a sum total of cross-sectional areas of the flow passages of the plurality of sub-heat transfer tubes is represented as AT_2, a flow rate [kG/h] of all refrigerant flowing through the main heat exchanger is represented as Gr_1, a flow rate [kG/h] of all refrigerant flowing through the sub-heat exchanger is represented as Gr_2, a gravitational acceleration [m/s^2] is represented as G, an equivalent diameter [m] of a cross-section of the flow passage of each of the plurality of main heat transfer tubes is represented as D_1, an equivalent diameter [m] of a cross-section of the flow passage of each of the plurality of sub-heat transfer tubes is represented as D_2, a density [kG/m^3] of liquid refrigerant flowing in the plurality of main heat transfer tubes is represented as ρL_1, a density [kG/m^3] of liquid refrigerant flowing in the plurality of sub-heat transfer tubes is represented as ρL_2, a density [kG/m^3] of gas refrigerant flowing in the plurality of main heat transfer tubes is represented as ρG_1, a density [kG/m^3] of gas refrigerant flowing in the plurality of sub-heat transfer tubes is represented as ρG_2, a quality [-] of refrigerant flowing in the main heat exchanger is represented as X_1, and a quality [-] of refrigerant flowing in the sub-heat exchanger is represented as X_2.

$$0.1 < N_2/(N_1 + N_2) < 0.4 \cdots (1)$$

$$0.03 < Ta_1/Ha_1 < 0.3 \cdots (2)$$

$$0.03 < Ta_2/Ha_2 < 0.3 \cdots (3)$$

$$AT_1 < Gr_1/(G \times D_1(\rho L_1 - \rho G_1))^{(1/2)} \times (X_1^{(1/2)} \times \rho G_1^{(-1/4)} + (1 - X_1)^{(1/2)} \times \rho L_1^{(-1/4)})^2 \cdots (4)$$

$$AT_2 < Gr_2/(G \times D_2(\rho L_2 - \rho G_2))^{(1/2)} \times (X_2^{(1/2)} \times \rho G_2^{(-1/4)} + (1 - X_2)^{(1/2)} \times \rho L_2^{(-1/4)})^2 \cdots (5)$$

Advantageous Effects of Invention

[0007] In the heat exchanger according to an embodiment of the present disclosure, the relationship between the number of the main heat transfer tubes and the number of the sub-heat transfer tubes satisfies Expression (1) below. In this heat exchanger, the main heat exchanger satisfies Expressions (2) and (4) below, while the sub-heat exchanger satisfies Expressions (3) and (5) below. The likelihood of stagnation and back flow of refrigerant is thus reduced when the refrigerant flows upward in the heat transfer tubes. Therefore, the heat exchanger has improved heat exchange performance without causing pressure loss of refrigerant in the heat transfer tubes.

$$0.1 < N_2/(N_1 + N_2) < 0.4 \cdots (1)$$

$$0.03 < Ta_1/Ha_1 < 0.3 \cdots (2)$$

$$0.03 < Ta_2/Ha_2 < 0.3 \cdots (3)$$

$$AT_1 < Gr_1/(G \times D_1(\rho L_1 - \rho G_1))^{(1/2)} \times (X_1^{(1/2)} \times \rho G_1^{(-1/4)} + (1 - X_1)^{(1/2)} \times \rho L_1^{(-1/4)})^2 \cdots (4)$$

$$AT_2 < Gr_2/(G \times D_2(\rho L_2 - \rho G_2))^{(1/2)} \times (X_2^{(1/2)} \times \rho G_2^{(-1/4)} + (1 - X_2)^{(1/2)} \times \rho L_2^{(-1/4)})^2 \cdots (5)$$

Brief Description of Drawings

[0008]

[Fig. 1] Fig. 1 is a circuit diagram illustrating an air-conditioning apparatus 1 according to Embodiment 1.
[Fig. 2] Fig. 2 is a perspective view illustrating a heat exchanger 7 according to Embodiment 1.
[Fig. 3] Fig. 3 is a plan view illustrating the heat exchanger 7 according to Embodiment 1.

[Fig. 4] Fig. 4 is a configuration diagram illustrating main heat transfer tubes 31 and a first main header 33 according to Embodiment 1.

[Fig. 5] Fig. 5 is a configuration diagram illustrating sub-heat transfer tubes 41 and a first sub-header 43 according to Embodiment 1.

[Fig. 6] Fig. 6 is a graph illustrating heat exchange performance of the heat exchanger 7 according to Embodiment 1.

[Fig. 7] Fig. 7 is a graph illustrating the conditions under which flooding occurs according to Embodiment 1.

Description of Embodiments

Embodiment 1

[0009] An air-conditioning apparatus 1 according to Embodiment 1 is described hereinafter with reference to the drawings. Fig. 1 is a circuit diagram illustrating the air-conditioning apparatus 1 according to Embodiment 1. As illustrated in Fig. 1, the air-conditioning apparatus 1 includes an outdoor unit 2, an indoor unit 3, and a refrigerant pipe 4. Note that Fig. 1 illustrates an example in which one indoor unit 3 is provided, however, two or more indoor units 3 may be provided.

(Outdoor unit 2, indoor unit 3, and refrigerant pipe 4)

[0010] The outdoor unit 2 includes a compressor 5, a flow switching device 6, a heat exchanger 7, an outdoor fan 8, and an expansion unit 9. The indoor unit 3 includes an indoor heat exchanger 11 and an indoor fan 12. The refrigerant pipe 4 connects the compressor 5, the flow switching device 6, the heat exchanger 7, the expansion unit 9, and the indoor heat exchanger 11 to form a refrigerant circuit in which refrigerant flows.

(Compressor 5, flow switching device 6, heat exchanger 7, outdoor fan 8, and expansion unit 9)

[0011] The compressor 5 is configured to suck refrigerant in a low-temperature and low-pressure state, compress the sucked refrigerant into a high-temperature and high-pressure state, and discharge the compressed refrigerant. The flow switching device 6 is configured to change the flow directions of refrigerant in the refrigerant circuit. For example, the flow switching device 6 is a four-way valve. The heat exchanger 7 is configured to exchange heat between refrigerant and outdoor air. The heat exchanger 7 operates as a condenser during cooling operation, and operates as an evaporator during heating operation. The outdoor fan 8 is a device to deliver outdoor air to the heat exchanger 7. The expansion unit 9 is a pressure reducing valve or an expansion valve to reduce the pressure of refrigerant and expand the refrigerant.

(Indoor heat exchanger 11 and indoor fan 12)

[0012] The indoor heat exchanger 11 is configured to exchange heat between room air and refrigerant. The indoor heat exchanger 11 operates as an evaporator during cooling operation, and operates as a condenser during heating operation. The indoor fan 12 is a device to deliver room air to the indoor heat exchanger 11.

(Cooling operation)

[0013] Operation of the air-conditioning apparatus 1 is described below. First, cooling operation is described. During cooling operation, refrigerant sucked into the compressor 5 is compressed by the compressor 5 into a high-temperature and high-pressure gas state and then discharged. The gas refrigerant in a high-temperature and high-pressure state discharged from the compressor 5 passes through the flow switching device 6 and flows into the heat exchanger 7, which operates as a condenser. Refrigerant flowing into the heat exchanger 7 exchanges heat with outdoor air delivered by the outdoor fan 8, and condenses into liquid. The refrigerant in a liquid state flows into the expansion unit 9, and is reduced in pressure and expanded, so that the refrigerant is brought into a low-temperature and low-pressure two-phase gas-liquid state. The refrigerant in the two-phase gas-liquid state flows into the indoor heat exchanger 11, which operates as an evaporator. Refrigerant flowing into the indoor heat exchanger 11 exchanges heat with room air delivered by the indoor fan 12, and evaporates into gas. At this time, the room air is cooled and thus cooling is performed in the room. Thereafter, the gas refrigerant having evaporated into a low-temperature and low-pressure state passes through the flow switching device 6 and is sucked into the compressor 5.

(Heating operation)

[0014] Next, heating operation is described. During heating operation, refrigerant sucked into the compressor 5 is compressed by the compressor 5 into a high-temperature and high-pressure gas state and then discharged. The high-temperature and high-pressure gas refrigerant discharged from the compressor 5 passes through the flow switching device 6 and flows into the indoor heat exchanger 11, which operates as a condenser. Refrigerant flowing into the indoor heat exchanger 11 exchanges heat with room air delivered by the indoor fan 12, and condenses into liquid. At this time, the indoor air is heated and thus heating is performed in the room. The refrigerant in a liquid state flows into the expansion unit 9, and is reduced in pressure and expanded, so that the refrigerant is brought into a low-temperature and low-pressure two-phase gas-liquid state. The refrigerant in the two-phase gas-liquid state flows into the heat exchanger 7, which operates as an evaporator. Refrigerant flowing into the heat exchanger 7 exchanges heat with outdoor air delivered by the outdoor fan 8, and evaporates into gas. Thereafter, the gas refrigerant having evaporated into a low-temperature and low-pressure state passes through the flow switching device 6 and is sucked into the compressor 5.

(Heat exchanger 7)

[0015] Fig. 2 is a perspective view illustrating the heat exchanger 7 according to Embodiment 1. Fig. 3 is a plan view illustrating the heat exchanger 7 according to Embodiment 1. The open arrows illustrated in Fig. 2 represent the flow of refrigerant when the heat exchanger 7 operates as an evaporator. The hatched arrow represents the flow of air passing through the heat exchanger 7. The configuration of the heat exchanger 7 is described below in detail. Note that the configuration equivalent to that of the heat exchanger 7 may be applied to the indoor heat exchanger 11. As illustrated in Fig. 2, the heat exchanger 7 includes a main heat exchanger 21 and a sub-heat exchanger 22. When the heat exchanger 7 operates as a condenser, the main heat exchanger 21 is located upstream of the sub-heat exchanger 22. When the heat exchanger 7 operates as a condenser, the sub-heat exchanger 22 operates as a subcooling device. Note that the heat exchanger 7 may be formed into an L-shape in top view such that the heat exchanger 7 extends along the back face and the side face of the housing of the outdoor unit 2. In this case, a portion of the heat exchanger 7 located beside the back face of the housing, and another portion of the heat exchanger 7 located beside the side face of the housing may be connected through a connection pipe, or may be formed integrally with each other.

(Main heat exchanger 21)

[0016] As illustrated in Fig. 2, the main heat exchanger 21 includes main heat transfer tubes 31, main fins 32, a first main header 33, a second main header 34, and a third main header 35. Each of the main heat transfer tubes 31 has a plurality of flow passages inside which refrigerant flows. For example, the main heat transfer tubes 31 are flat tubes. The main heat transfer tubes 31 extend in the up-down direction. The number of the main heat transfer tubes 31 provided in the main heat exchanger 21 is N_1. In the present Embodiment 1, the main heat transfer tubes 31 are arranged in two parallel lines, which are a first line and a second line. Note that the main heat transfer tubes 31 may be arranged only in a single line. Each of the main fins 32 is, for example, a corrugated fin, and the main fins 32 are provided to the main heat transfer tubes 31 and help heat exchange between air and refrigerant flowing inside the main heat transfer tubes 31.

[0017] One end portion of each of the main heat transfer tubes 31 arranged in the first line is inserted into the first main header 33. The refrigerant pipe 4 is connected to the first main header 33. When the heat exchanger 7 operates as a condenser, the first main header 33 distributes refrigerant flowing from the refrigerant pipe 4 to the main heat transfer tubes 31 arranged in the first line. When the heat exchanger 7 operates as an evaporator, the first main header 33 allows refrigerant, having joined together from the main heat transfer tubes 31 arranged in the first line, to flow out to the refrigerant pipe 4.

[0018] The second main header 34 is provided to be opposite to the first main header 33 and the third main header 35. The other end portion of each of the main heat transfer tubes 31 arranged in the first line and the second line is inserted into the second main header 34. When the heat exchanger 7 operates as a condenser, the second main header 34 distributes refrigerant, having joined together from the main heat transfer tubes 31 arranged in the first line, to the main heat transfer tubes 31 arranged in the second line. When the heat exchanger 7 operates as an evaporator, the second main header 34 distributes refrigerant, having joined together from the main heat transfer tubes 31 arranged in the second line, to the main heat transfer tubes 31 arranged in the first line.

[0019] The third main header 35 is provided parallel to the first main header 33. One end portion of each of the main heat transfer tubes 31 arranged in the second line is inserted into the third main header 35. When the heat exchanger 7 operates as a condenser, the third main header 35 allows refrigerant, flowing from the main heat transfer tubes 31 arranged in the second line, to flow into the third sub-header 45 of the sub-heat exchanger 22, which is described later. When the heat exchanger 7 operates as an evaporator, the third main header 35 distributes refrigerant flowing from the third sub-header 45 to the main heat transfer tubes 31 arranged in the second line. Note that, in the main heat exchanger 21, the first main header 33 and the third main header 35 may be integrated into one header, and the main heat exchanger 21 may include a partition portion (not illustrated) at the central portion of the one header to partition the internal space into sub-spaces.

[0020] Fig. 4 is a configuration diagram illustrating the main heat transfer tubes 31 and the first main header 33 according to Embodiment 1. Fig. 4 illustrates the cross-section of the first main header 33 taken along the A-A direction illustrated in Fig. 3. With reference to Fig. 4, dimensions of the parts of the main heat exchanger 21, properties of refrigerant flowing in the main heat transfer tubes 31, and other specifications are explained below. Note that, in the explanations below, the term "cross-section" refers to a cross-section perpendicular to the direction in which the flow passage formed in the main heat transfer tube 31 extends. As illustrated in Fig. 4, the equivalent diameter [m] of the cross-section of the flow passage of each of the main heat transfer tubes 31 is represented as D_1. The cross-sectional area of the flow passages of each of the main heat transfer tubes 31 is represented as Ta_1. The cross-sectional area Ta_1 of the flow passages is the sum of the cross-sectional areas of the plurality of flow passages formed in the main heat transfer tube 31.

[0021] The sum total of the cross-sectional areas of the flow passages of the main heat transfer tubes 31 is represented as AT_1. The sum total AT_1 of the cross-sectional areas of the flow passages refers to a value obtained by multiplying the cross-sectional area Ta_1 of the flow passages of a single main heat transfer tube 31 by the number N_1 of the main heat transfer tubes 31. The cross-sectional area of the first main header 33 per each of the main heat transfer tubes 31 is represented as Ha_1. The cross-sectional area Ha_1 of the first main header 33 per each of the main heat transfer tubes 31 refers to a value obtained by dividing the cross-sectional area of the interior space of the first main header 33 by the number N_1 of the main heat transfer tubes 31. The cross-sectional area Ha_1 of the first main header 33 per each of the main heat transfer tubes 31 refers to the area of the region illustrated in Fig. 4 that is hatched laterally to the sheet plane. The main heat exchanger 21 satisfies Expression (2) below.

[Expression 6]

$$0.03 < Ta_1/Ha_1 < 0.3 \cdots (2)$$

[0022] The main heat exchanger 21 also satisfies Expression (4) below, where the flow rate [kG/h] of all refrigerant flowing through the main heat exchanger 21 is represented as Gr_1, the density [kG/m^3] of liquid refrigerant flowing in the main heat transfer tubes 31 is represented as ρL_1, the density [kG/m^3] of gas refrigerant flowing in the main heat transfer tubes 31 is represented as ρG_1, the quality [-] of refrigerant flowing in the main heat exchanger 21 is represented as X_1, and the gravitational acceleration [m/s^2] is represented as G.

[Expression 7]

$$AT_1 < Gr_1/(G \times D_1 \times (\rho L_1 - \rho G_1))^{(1/2)} \times (X_1{}^{(1/2)} \times \rho G_1{}^{(-1/4)} + (1 - X_1)^{(1/2)} \times \rho L_1{}^{(-1/4)})^2 \cdots (4)$$

(Sub-heat exchanger 22)

[0023] As illustrated in Fig. 2, the sub-heat exchanger 22 includes sub-heat transfer tubes 41, sub-fins 42, a first sub-header 43, a second sub-header 44, and a third sub-header 45. Each of the sub-heat transfer tubes 41 has a plurality of flow passages inside which refrigerant flows. For example, the sub-heat transfer tubes 41 are flat tubes. The sub-heat transfer tubes 41 extend in the up-down direction. The number of the sub-heat transfer tubes 41 provided in the sub-heat exchanger 22 is N_2. In the present Embodiment 1, the sub-heat transfer tubes 41 are arranged in two parallel lines, which are a first line and a second line. Note that the sub-heat transfer tubes 41 may be arranged only in a single line. Each of the sub-fins 42 is, for example, a corrugated fin, and the sub-fins 42 are provided to the sub-heat transfer tubes 41 and help heat exchange between air and refrigerant flowing inside the sub-heat transfer tubes 41.

[0024] One end portion of each of the sub-heat transfer tubes 41 arranged in the first line is inserted into the first sub-header 43. The first sub-header 43 is connected to the first main header 33 through a first partition plate 23. The first partition plate 23 partitions the internal space into the first main header 33 and the first sub-header 43. The refrigerant pipe 4 is connected to the first sub-header 43. When the heat exchanger 7 operates as an evaporator, the first sub-header 43 distributes refrigerant flowing from the refrigerant pipe 4 to the sub-heat transfer tubes 41 arranged in the first line. When the heat exchanger 7 operates as a condenser, the first sub-header 43 allows refrigerant, having joined together from the sub-heat transfer tubes 41 arranged in the first line, to flow out to the refrigerant pipe 4.

[0025] The second sub-header 44 is provided to be opposite to the first sub-header 43 and the third sub-header 45. The other end portion of each of the sub-heat transfer tubes 41 arranged in the first line and the second line is inserted into the second sub-header 44. The second sub-header 44 is connected to the second main header 34 through a second partition plate 24. The second partition plate 24 partitions the internal space into the second main header 34 and the second sub-header 44. When the heat exchanger 7 operates as an evaporator, the second sub-header 44 distributes refrigerant, having joined together from the sub-heat transfer tubes 41 arranged in the first line, to the sub-heat transfer tubes 41 arranged in the second line. When the heat exchanger 7 operates as a condenser, the second sub-header 44 distributes refrigerant, having joined together from the sub-heat transfer tubes 41 arranged in the second line, to the sub-heat transfer tubes 41 arranged in the first line.

[0026] The third sub-header 45 is provided parallel to the first sub-header 43. One end portion of each of the sub-heat transfer tubes 41 arranged in the second line is inserted into the third sub-header 45. The third sub-header 45 is connected to the third main header 35 such that their internal spaces communicate with each other. When the heat exchanger 7 operates as an evaporator, the third sub-header 45 allows refrigerant, flowing from the sub-heat transfer tubes 41 arranged in the second line, to flow into the third main header 35 of the main heat exchanger 21. When the heat exchanger 7 operates as a condenser, the third sub-header 45 distributes refrigerant flowing from the third main header 35 to the sub-heat transfer tubes 41 arranged in the second line. Note that, in the sub-heat exchanger 22, the first sub-header 43 and the third sub-header 45 may be integrated into one header, and the sub-heat exchanger 22 may include a partition portion (not illustrated) at the central portion of the one header to partition the internal space into sub-spaces.

[0027] Fig. 5 is a configuration diagram illustrating the sub-heat transfer tubes 41 and the first sub-header 43 according to Embodiment 1. Fig. 5 illustrates the cross-section of the first sub-header 43 taken along the A-A direction illustrated in Fig. 3. With reference to Fig. 5, dimensions of the parts of the sub-heat exchanger 22, properties of refrigerant flowing in the sub-heat transfer tubes 41, and other specifications are explained below. Note that, in the explanations below, the term "cross-section" refers to a cross-section perpendicular to the direction in which the flow passage formed in the sub-heat transfer tube 41 extends. In the explanations below, the configuration of the sub-heat exchanger 22 denoted with the suffix "$_2$" is equivalent to the corresponding configuration of the main heat exchanger 21 denoted with the suffix "$_1$" in place of the suffix "$_2$." The equivalent diameter [m] of the cross-section of the flow passage of each of the sub-heat transfer tubes 41 is represented as D_2. The cross-sectional area of the flow passages of each of the sub-heat transfer tubes 41 is represented as Ta_2. The cross-sectional area Ta_2 of the flow passages is the sum of the cross-sectional areas of the plurality of flow passages formed in the sub-heat transfer tube 41.

[0028] The sum total of the cross-sectional areas of the flow passages of the sub-heat transfer tubes 41 is represented as AT_2. The sum total AT_2 of the cross-sectional areas of the flow passages refers to a value obtained by multiplying the cross-sectional area Ta_2 of the flow passages of a single sub-heat transfer tube 41 by the number N_2 of the sub-heat transfer tubes 41. The cross-sectional area of the first sub-header 43 per each of the sub-heat transfer tubes 41 is represented as Ha_2. The cross-sectional area Ha_2 of the first sub-header 43 per each of the sub-heat transfer tubes 41 refers to a value obtained by dividing the cross-sectional area of the interior space of the first sub-header 43 by the number N_2 of the sub-heat transfer tubes 41. The cross-sectional area Ha_2 of the first sub-header 43 per each of the sub-heat transfer tubes 41 refers to the area of the region illustrated in Fig. 5 that is hatched laterally to the sheet plane. The sub-heat exchanger 22 satisfies Expression (3) below.

[Expression 8]

$$0.03 < Ta_2/Ha_2 < 0.3 \cdots (3)$$

[0029] The sub-heat exchanger 22 also satisfies Expression (5) below, where the flow rate [kG/h] of all refrigerant flowing through the sub-heat exchanger 22 is represented as Gr_2, the density [kG/m^3] of liquid refrigerant flowing in the sub-heat transfer tubes 41 is represented as ρL_2, the density [kG/m^3] of gas refrigerant flowing in the sub-heat transfer tubes 41 is represented as ρG_2, and the quality [-] of refrigerant flowing in the sub-heat exchanger 22 is represented as X_2.

[Expression 9]

$$AT_2 < Gr_2/(G \times D_1 \times (\rho L_1 - \rho G_2))^{(1/2)} \times (X_2^{(1/2)} \times \rho G_2^{(-1/4)} + (1 - X_2)^{(1/2)} \times \rho L_2^{(-1/4)})^2 \cdots (5)$$

[0030] Fig. 6 is a graph illustrating heat exchange performance of the heat exchanger 7 according to Embodiment 1. The vertical axis illustrated in Fig. 6 represents heat exchange performance of the heat exchanger 7. The horizontal axis illustrated in Fig. 6 represents the ratio of the sub-heat exchanger 22 in the heat exchanger 7. The ratio of the sub-heat exchanger 22 refers to the ratio of the number N_2 of the sub-heat transfer tubes 41 to the total number $N_1 + N_2$ of the main heat transfer tubes 31 and the sub-heat transfer tubes 41. As illustrated in Fig. 6, the heat exchanger 7 has high heat exchange efficiency when the ratio of the sub-heat exchanger 22 ranges from 10% to 40%. The heat exchanger 7 satisfies Expression (1) below for the number of the main heat transfer tubes 31 and the number of the sub-heat transfer tubes 41. Because of this expression, the heat exchanger 7 achieves high heat exchange performance.

[Expression 10]

$$0.1 < N_2/(N_1 + N_2) < 0.4 \cdots (1)$$

[0031] Fig. 7 is a graph illustrating the conditions under which flooding occurs according to Embodiment 1. The flooding is a phenomenon in which when refrigerant in a two-phase gas-liquid state flows upward inside the heat transfer tubes, portion of the refrigerant in a liquid state in the vicinity of the gas-liquid interface flows backward in the reverse direction to the flow of another portion of the refrigerant in a gas state, so that the refrigerant in a two-phase gas-liquid state stagnates in the heat transfer tubes. If the flooding has occurred in the heat transfer tubes, pressure loss of refrigerant flowing in the heat transfer tubes will be caused. With reference to Fig. 7, an explanation is given for the fact that the likelihood of stagnation and back flow of refrigerant is reduced when the refrigerant flows upward in the main heat transfer tubes 31 and the sub-heat transfer tubes 41 according to Embodiment 1. Note that, in the explanations below, the suffixes "$_1$" and "$_2$" are appropriately omitted. The description in which the suffixes "$_1$" and "$_2$" are omitted explains each of the main heat exchanger 21 and the sub-heat exchanger 22.

[0032] Fig. 7 illustrates the results of the examination of the conditions under which the flooding occurs when the velocity of refrigerant flowing in the heat transfer tubes is varied in the heat exchanger 7 that satisfies Expressions (1) to (3). The vertical axis illustrated in Fig. 7 represents the dimensionless quantity $jG^{*(1/2)}$ derived from Expression (6) below, where the flow rate [m/s] of gas refrigerant flowing in the heat transfer tubes is represented as jG. The horizontal axis illustrated in Fig. 7 represents the dimensionless quantity $jL^{*(1/2)}$ derived from Expression (7) below, where the flow rate [m/s] of liquid refrigerant flowing in the heat transfer tubes is represented as jL. The point of intersection of the vertical line and the horizontal line represents the dimensionless quantity $C = jG^{*(1/2)} + jL^{*(1/2)}$.

[Expression 11]

$$jG^{*} = jG \times (\rho G/(G \times D \times (\rho L - \rho G)))^{(1/2)} \cdots (6)$$

[Expression 12]

$$jL^{*} = jL \times (\rho L/(G \times D \times (\rho L - \rho G)))^{(1/2)} \cdots (7)$$

[0033] The up-pointing triangle marks and the plus signs illustrated in Fig. 7 represent the values of $jG^{*(1/2)}$ and the values of $jL^{*(1/2)}$ when the flooding has occurred. In addition, the square marks and the down-pointing triangle marks illustrated in Fig. 7 represent the values of $jG^{*(1/2)}$ and the values of $jL^{*(1/2)}$ when the flooding has ended. That is, Fig. 7 shows that the flooding occurs within the range of $0.88 < C \leq 1$. It is also known that, in a case of $C \leq 0.88$, liquid refrigerant flows downward throughout the heat transfer tubes to the bottom. Therefore, where the heat exchanger 7 satisfies $C > 1$, that is, Expression (8) below, when refrigerant flows upward in the main heat transfer tubes 31 and the sub-heat transfer tubes 41, the likelihood of stagnation and back flow of the refrigerant is reduced.

[Expression 13]

$$jG^{*(1/2)} + jL^{*(1/2)} > 1 \cdots (8)$$

[0034] Where the flow rate [kg/h] of liquid refrigerant flowing in the heat transfer tubes is represented as GL, and the flow rate [kg/h] of gas refrigerant flowing in the heat transfer tubes is represented as GG, Expressions (9) to (13) below are satisfied.

[Expression 14]

$$GG = G \times X \cdots (9)$$

[Expression 15]

$$GL = G \times (1 - X) \cdots (10)$$

[Expression 16]

$$G = Gr/AT \cdots (11)$$

[Expression 17]

$$jG = GG/\rho G \cdots (12)$$

[Expression 18]

$$jL = GL/\rho L \cdots (13)$$

[0035] On the basis of Expressions (9) and (11), Expression (14) below is satisfied. On the basis of Expressions (10) and (11), Expression (15) below is satisfied.
[Expression 19]

$$GG = (Gr \times X)/AT \cdots (14)$$

[Expression 20]

$$GL = (Gr \times (1 - X))/AT \cdots (15)$$

[0036] On the basis of Expressions (12) and (14), Expression (16) below is satisfied. On the basis of Expressions (13) and (15), Expression (17) below is satisfied.
[Expression 21]

$$jG = (Gr \times X)/(AT \times \rho G) \cdots (16)$$

[Expression 22]

$$jL = (Gr \times (1 - X))/(AT \times \rho L) \cdots (17)$$

[0037] On the basis of Expressions (6) to (8), (16), and (17), Expression (18) below is satisfied. Expression (18) corresponds to Expressions (4) and (5). That is, the main heat exchanger 21 and the sub-heat exchanger 22 according to Embodiment 1 meet the configuration with C > 1 derived from the experiment illustrated in Fig. 7. Because of this configuration, the main heat exchanger 21 and the sub-heat exchanger 22 according to Embodiment 1 reduce the likelihood of stagnation and back flow of refrigerant when the refrigerant flows upward in the main heat transfer tubes 31 and the sub-heat transfer tubes 41.
[Expression 23]

$$AT < Gr/(G \times D(\rho L - \rho G))^{(1/2)} \times (X^{(1/2)} \times \rho G^{(-1/4)} + (1 - X)^{(1/2)} \times \rho L^{(-1/4)})^{2} \cdots (18)$$

[0038] In the heat exchanger according to the present disclosure, the relationship between the number of the main heat transfer tubes 31 and the number of the sub-heat transfer tubes 41 satisfies Expression (1) below. In this heat exchanger, the main heat exchanger 21 satisfies Expressions (2) and (4) below, while the sub-heat exchanger 22 satisfies Expressions (3) and (5) below. The likelihood of stagnation and back flow of refrigerant is thus reduced when the refrigerant flows upward in the heat transfer tubes. Therefore, the heat exchanger has improved heat exchange performance without causing pressure loss of refrigerant in the heat transfer tubes.

$$0.1 < N_2/(N_1 + N_2) < 0.4 \cdots (1)$$

$$0.03 < Ta_1/Ha_1 < 0.3 \cdots (2)$$

$$0.03 < Ta_2/Ha_2 < 0.3 \cdots (3)$$

$$AT_1 < Gr_1/(G \times D_1 \times (\rho L_1 - \rho G_1))^{(1/2)} \times (X_1^{(1/2)} \times \rho G_1^{(-1/4)} + (1 - X_1)^{(1/2)} \times \rho L_1^{(-1/4)})^2 \cdots (4)$$

$$AT_2 < Gr_2/(G \times D_2 \times (\rho L_2 - \rho G_2))^{(1/2)} \times (X_2^{(1/2)} \times \rho G_2^{(-1/4)} + (1 - X_2)^{(1/2)} \times \rho L_2^{(-1/4)})^2 \cdots (5)$$

[0039] Since no flooding occurs in the main heat exchanger 21 and the sub-heat exchanger 22, the flow rate of refrigerant does not decrease. This allows the heat exchanger 7 to have improved condensation performance of the sub-heat exchanger 22 even when the heat exchanger 7 operates as a condenser and the sub-heat exchanger 22 operates as a subcooling device.

Reference Signs List

[0040] 1: air-conditioning apparatus, 2: outdoor unit, 3: indoor unit, 4: refrigerant pipe, 5: compressor, 6: flow switching device, 7: heat exchanger, 8: outdoor fan, 9: expansion unit, 11: indoor heat exchanger, 12: indoor fan, 21: main heat exchanger, 22: sub-heat exchanger, 23: first partition plate, 24: second partition plate, 31: main heat transfer tube, 32: main fin, 33: first main header, 34: second main header, 35: third main header, 41: sub-heat transfer tube, 42: sub-fin, 43: first sub-header, 44: second sub-header, 45: third sub-header

Claims

1. A heat exchanger comprising:

a main heat exchanger; and
a sub-heat exchanger connected to the main heat exchanger,
the main heat exchanger including
a plurality of main heat transfer tubes extending in an up-down direction, each of the plurality of main heat transfer tubes having a flow passage inside which refrigerant flows,
a first main header into which one end portion of each of the plurality of main heat transfer tubes is inserted,
main fins provided to the plurality of main heat transfer tubes and helping heat exchange between air and refrigerant flowing inside the plurality of main heat transfer tubes, and
a second main header into which an other end portion of each of the plurality of main heat transfer tubes is inserted, the second main header being opposite to the first main header,
the sub-heat exchanger including
a plurality of sub-heat transfer tubes extending in an up-down direction, each of the plurality of sub-heat transfer tubes having a flow passage inside which refrigerant flows,
sub-fins provided to the plurality of sub-heat transfer tubes and helping heat exchange between air and refrigerant flowing inside the plurality of sub-heat transfer tubes,
a first sub-header into which one end portion of each of the plurality of sub-heat transfer tubes is inserted, and
a second sub-header into which an other end portion of each of the plurality of sub-heat transfer tubes is inserted, the second sub-header being opposite to the first sub-header,
the heat exchanger satisfying Expression (1) below, where the number of the plurality of main heat transfer tubes is represented as N_1, and
the number of the plurality of sub-heat transfer tubes is represented as N_2,
the heat exchanger satisfying Expressions (2) and (3) below, where
a cross-sectional area of the flow passage of each of the plurality of main heat transfer tubes is represented as Ta_1,
a cross-sectional area of the flow passage of each of the plurality of sub-heat transfer tubes is represented as Ta_2,
a cross-sectional area of the first main header per each of the plurality of main heat transfer tubes is represented as Ha_1, and
a cross-sectional area of the first sub-header per each of the plurality of sub-heat transfer tubes is represented as Ha_2,
the heat exchanger satisfying Expressions (4) and (5) below, where
a sum total of cross-sectional areas of the flow passages of the plurality of main heat transfer tubes is represented as AT_1,
a sum total of cross-sectional areas of the flow passages of the plurality of sub-heat transfer tubes is represented as AT_2,
a flow rate [kG/h] of all refrigerant flowing through the main heat exchanger is represented as Gr_1,

a flow rate [kG/h] of all refrigerant flowing through the sub-heat exchanger is represented as Gr_2,
a gravitational acceleration [m/s²] is represented as G,
an equivalent diameter [m] of a cross-section of the flow passage of each of the plurality of main heat transfer tubes is represented as D_1,
an equivalent diameter [m] of a cross-section of the flow passage of each of the plurality of sub-heat transfer tubes is represented as D_2,
a density [kG/m³] of liquid refrigerant flowing in the plurality of main heat transfer tubes is represented as ρL_1,
a density [kG/m³] of liquid refrigerant flowing in the plurality of sub-heat transfer tubes is represented as ρL_2,
a density [kG/m³] of gas refrigerant flowing in the plurality of main heat transfer tubes is represented as ρG_1,
a density [kG/m³] of gas refrigerant flowing in the plurality of sub-heat transfer tubes is represented as ρG_2,
a quality [-] of refrigerant flowing in the main heat exchanger is represented as X_1, and
a quality [-] of refrigerant flowing in the sub-heat exchanger is represented as X_2.
[Expression 1]

$$0.1 < N_2/(N_1 + N_2) < 0.4 \cdots (1)$$

[Expression 2]

$$0.03 < Ta_1/Ha_1 < 0.3 \cdots (2)$$

[Expression 3]

$$0.03 < Ta_2/Ha_2 < 0.3 \cdots (3)$$

[Expression 4]

$$AT_1 < Gr_1/(G \times D_1(\rho L_1 - \rho G_1))^{(1/2)} \times (X_1^{(1/2)} \times \rho G_1^{(-1/4)} + (1 - X_1)^{(1/2)} \times \rho L_1^{(-1/4)})^2 \cdots (4)$$

[Expression 5]

$$AT_2 < Gr_2/(G \times D_2(\rho L_2 - \rho G_2))^{(1/2)} \times (X_2^{(1/2)} \times \rho G_2^{(-1/4)} + (1 - X_2)^{(1/2)} \times \rho L_2^{(-1/4)})^2 \cdots (5)$$

2. An air-conditioning apparatus comprising:

a compressor configured to compress refrigerant;
the heat exchanger of claim 1;
an expansion unit configured to expand refrigerant; and
a heat exchanger configured to operate as a condenser when the heat exchanger of claim 1 operates as an evaporator, and configured to operate as an evaporator when the heat exchanger of claim 1 operates as a condenser.

FIG. 1

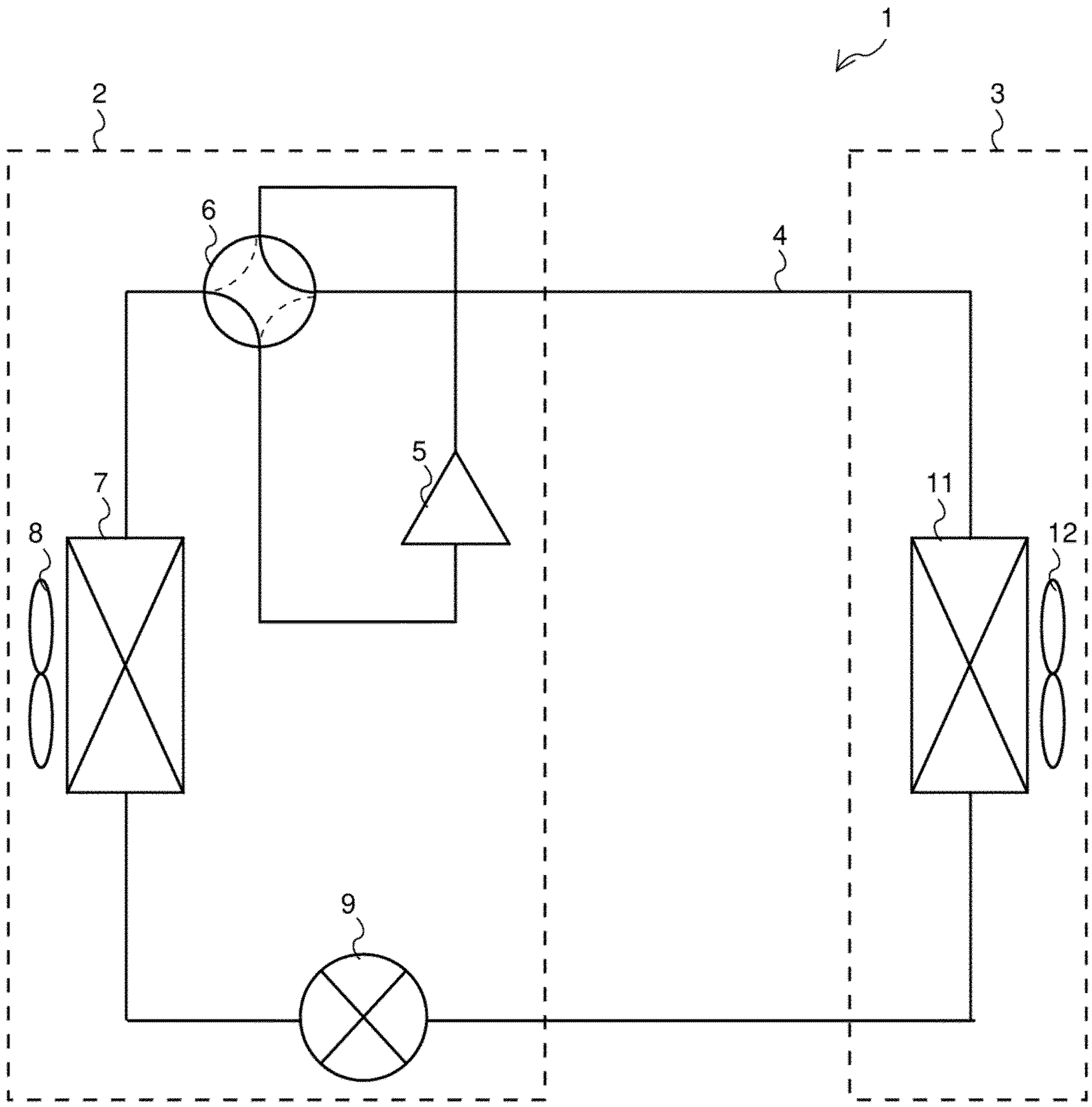


FIG. 2

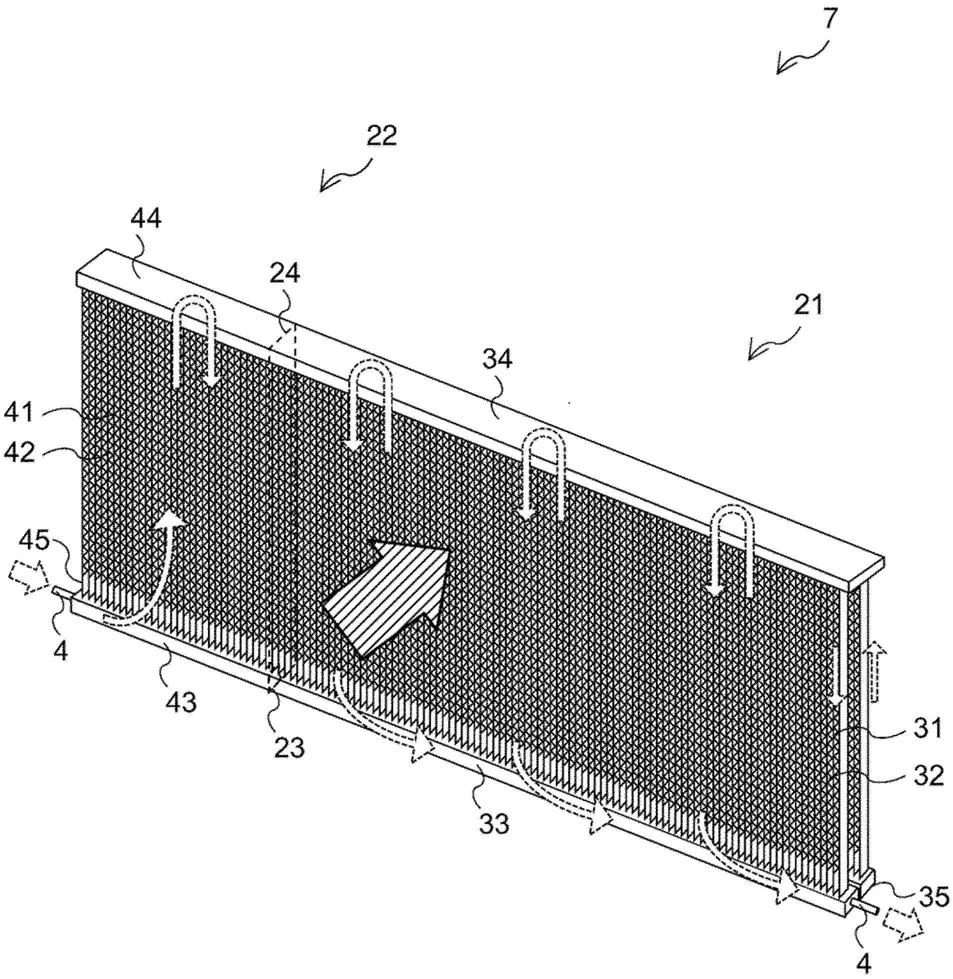


FIG. 3

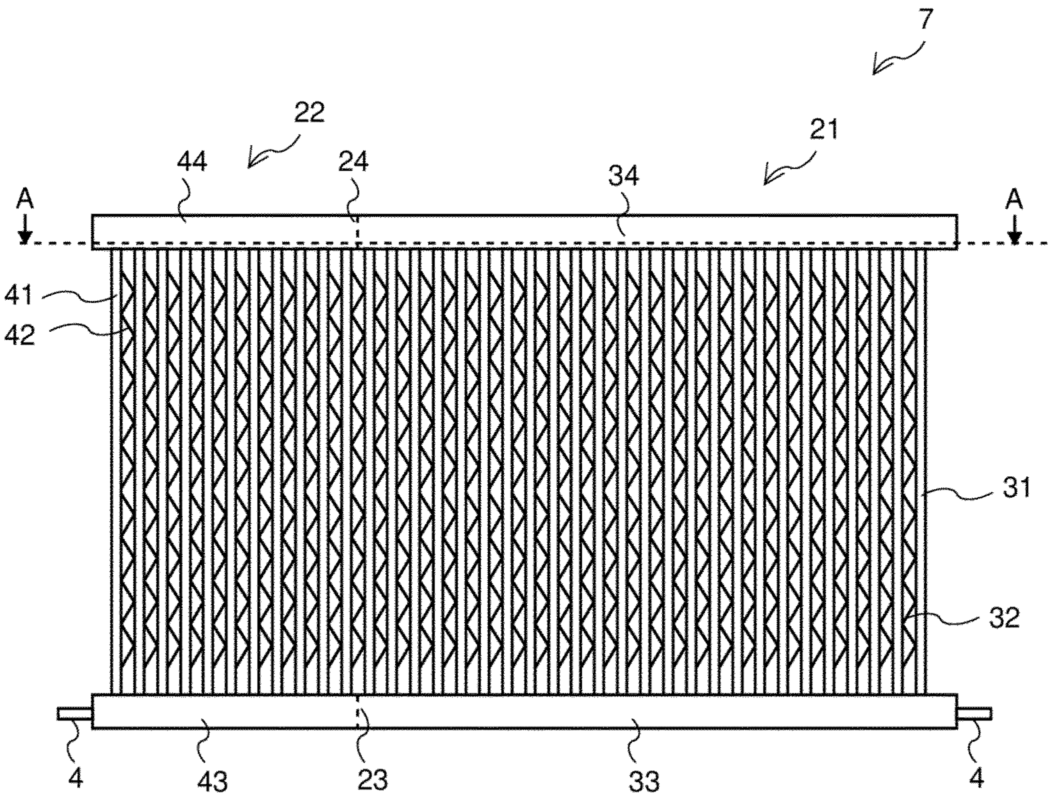


FIG. 4

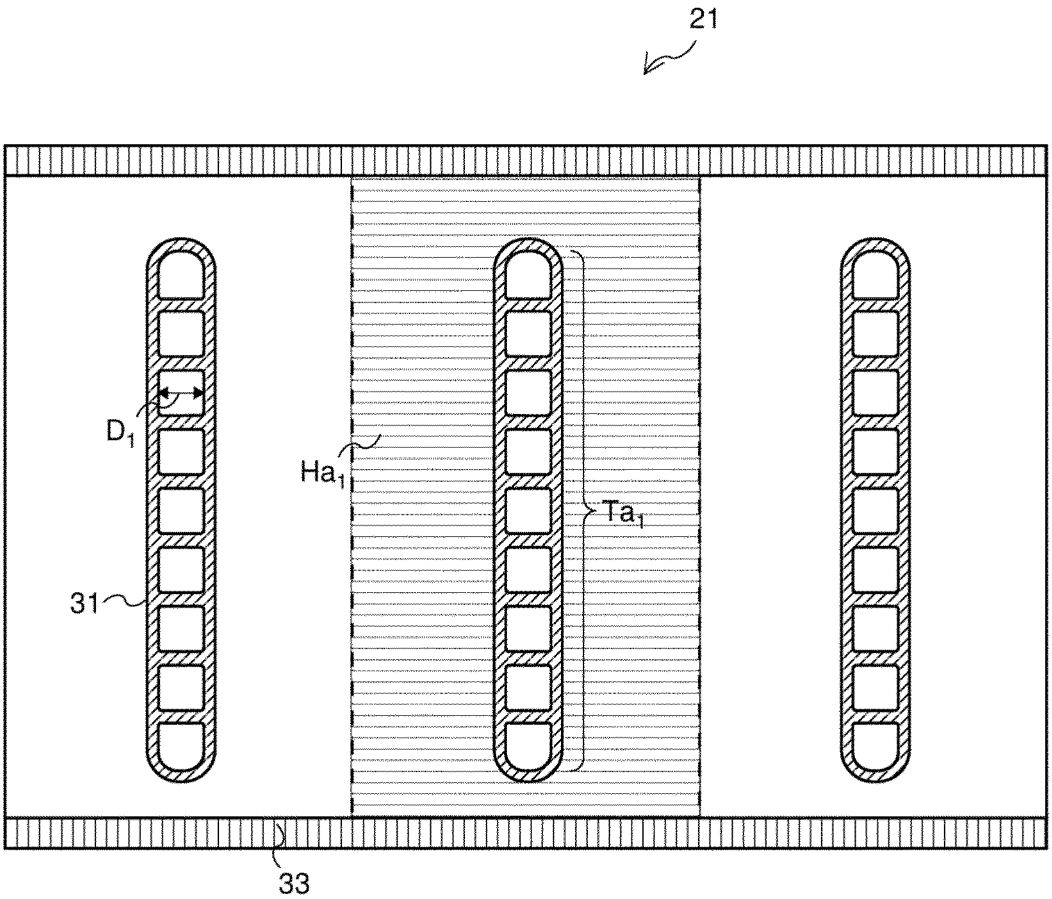


FIG. 5

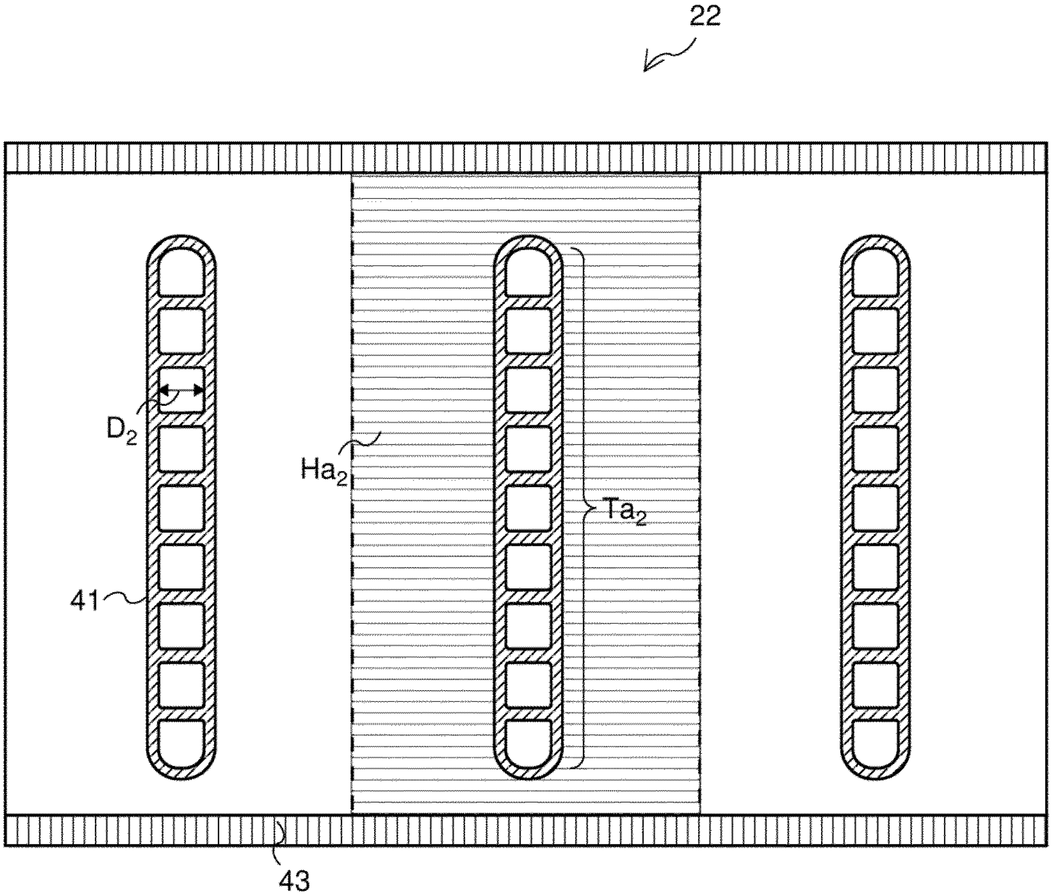


FIG. 6

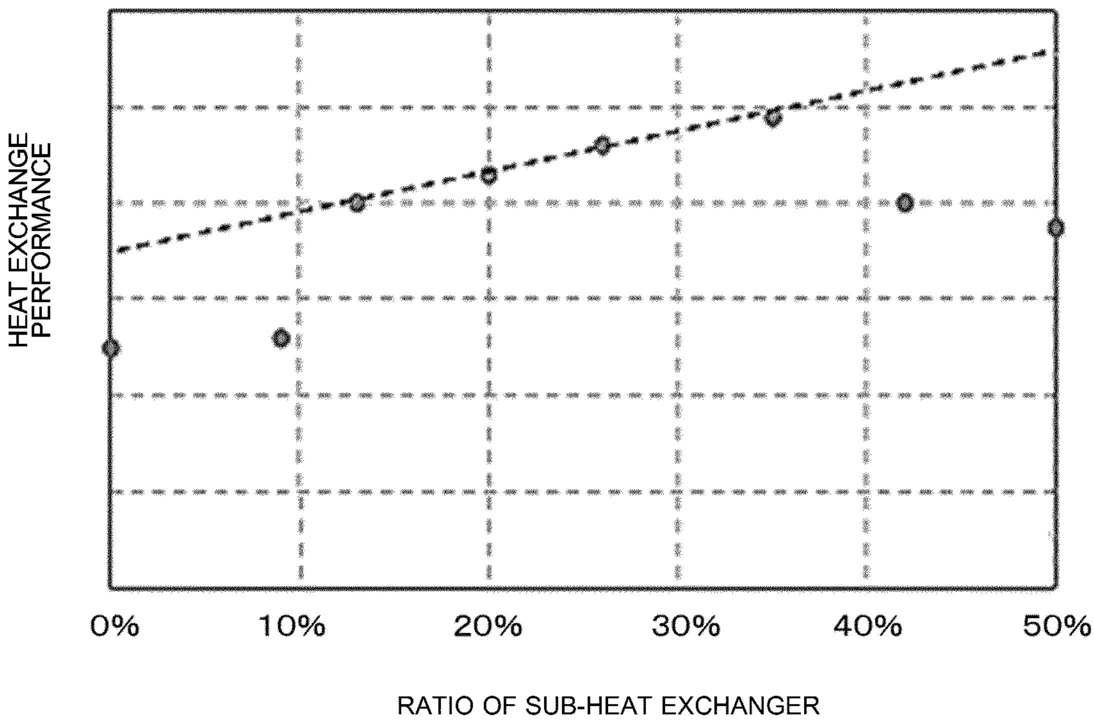
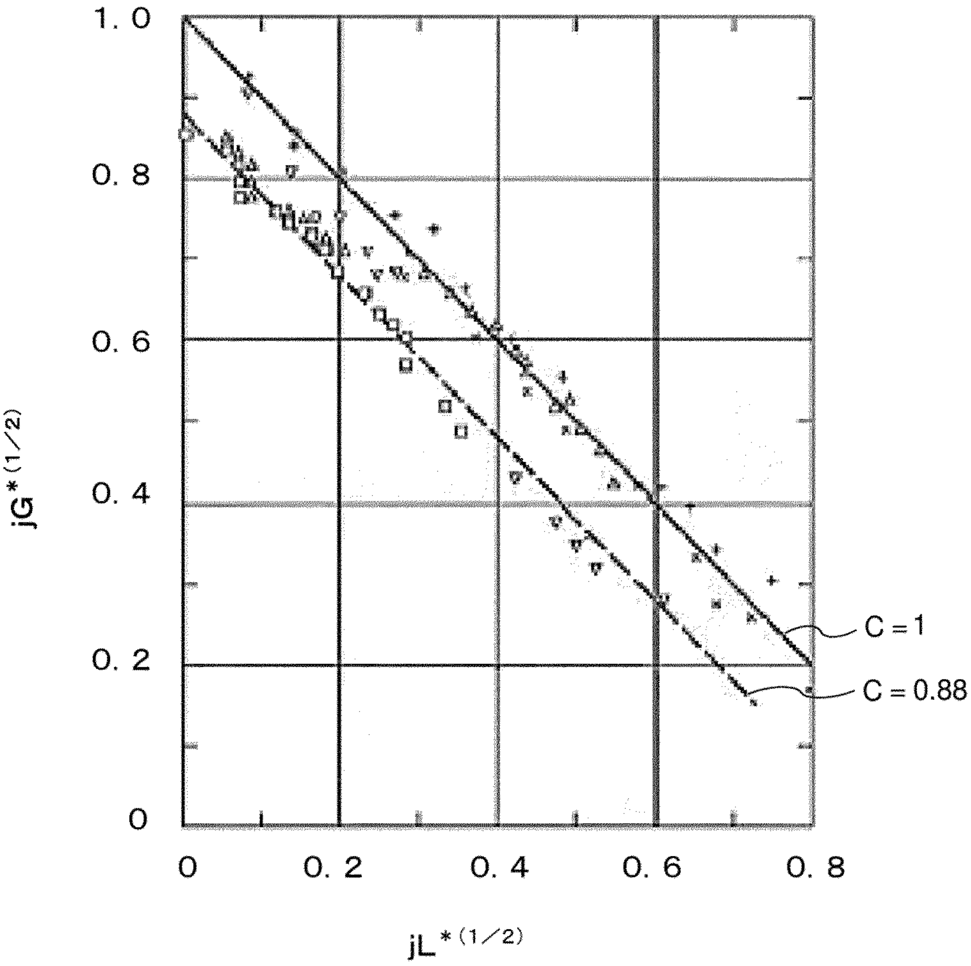

HEAT EXCHANGE PERFORMANCE
0%
10%
20%
30%
40%
50%
RATIO OF SUB-HEAT EXCHANGER

FIG. 7



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2020/020348

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. F25B39/00(2006.01)i, F28D1/04(2006.01)i, F28F9/02(2006.01)i
FI: F28F9/02 301E, F28D1/04 Z, F25B39/00 C, F28F9/02 301D

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. F25B39/00, F28D1/04, F28D1/053, F28F9/02

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 1971-2020
Registered utility model specifications of Japan 1996-2020
Published registered utility model applications of Japan 1994-2020

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2018/047332 A1 (MITSUBISHI ELECTRIC CORP.) 15 March 2018, entire text, all drawings	1-2
A	JP 2017-116152 A (SANDEN HOLDINGS CORP.) 29 June 2017, entire text, all drawings	1-2
A	WO 2015/125743 A1 (MITSUBISHI ELECTRIC CORP.) 27 August 2015, entire text, all drawings	1-2
A	JP 4686062 B2 (SHOWA DENKO KABUSHIKI KAISHA) 18 May 2011, entire text, all drawings	1-2

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Date of the actual completion of the international search	Date of mailing of the international search report
27.07.2020	04.08.2020

Name and mailing address of the ISA/	Authorized officer
Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Telephone No.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2020/020348

Patent Documents referred to in the Report	Publication Date	Patent Family	Publication Date
WO 2018/047332 A1	15.03.2018	US 2019/0234626 A1 entire text, all drawings EP 3511668 A1 CN 109690224 A	
JP 2017-116152 A	29.06.2017	WO 2017/110474 A1	
WO 2015/125743 A1	27.08.2015	US 2017/0167761 A1 entire text, all drawings EP 3109567 A1 CN 106030219 A	
JP 4686062 B2	18.05.2011	JP 2002-81795 A US 2002/0020521 A1 entire text, all drawings EP 1167911 A2 KR 10-2002-0001581 A	

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 4686062 B **[0003]**