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NOISE REDUCTION TECHNOLOGY WITH POROUS METAL FOR REFRIGERANT TWO-PHASE FLOW THROUGH THE EXPANSION VALVE

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ABSTRACT

Refrigerant gas-liquid two- phase flow through the expansion valve makes noise. This report introduces new noise reduction technology with porous metal for refrigerant two-phase flow. We visualized the test section of the orifice using as the expansion valve and measured noise level in the orifice with or without porous metal. The noise level of the split type room air-conditioner was measured installing the orifice into the indoor unit. The testing results show that porous metal of upstream of the orifice mixes vapor and liquid and that of downstream of it reduces pressure fluctuation of two-phase flow, therefore noise reduction is achieved.

1. INTRODUCTION

It is important to control both temperature and humidity achieving comfortable air-conditioning in Japan where is high temperature and humidity at summer time. Re-heat refrigerant cycling dehumidification operation is able to control both temperature and humidity. In this operation, the indoor heat exchanger is divided into a condenser and an evaporator by the expansion valve. In the conventional air-conditioners, since the expansion valve disposed in the indoor unit, large refrigerant flow noise is produced when the two-phase refrigerant passes through the orifice and the indoor silent environment is deteriorated thereby. This report introduces new noise reduction technology of refrigerant two-phase flow for the expansion valve with porous metal into the indoor unit with the re-heat refrigerant cycling dehumidification.

2. THE CONDITION OF REFRIGERANT FLOW NOISE

Figure 1 shows the refrigerant circuit diagram of the split type room air-conditioner with re-heat refrigerant cycling dehumidification operation. The indoor heat exchanger is divided into a first heat exchanger for condenser and a second heat exchanger for evaporator by the expansion valve. The operation in cooling and dehumidifying will be explained using a pressure-enthalpy diagram shown in Figure 2.

In the cooling operation, the outdoor expansion valve is main throttling device. The high-pressure and high-temperature vapor refrigerant (point 2) discharged from the compressor passes through the 4-way valve, exchanges heat with the outside air in the outdoor heat exchanger and is condensed so as to be made into a condensed state (point 5’). The condensed high-pressure liquid refrigerant is reduced in pressure in the outdoor expansion valve and flows into the first indoor heat exchanger as a low-pressure two-phase refrigerant (point 6’). The low-pressure vapor refrigerant ejected from the second indoor heat exchanger as an evaporator returns to the compressor again through the 4-way valve (point 1). In this operation, the refrigerant does not throttle in the indoor expansion valve.

In the dehumidifying operation, indoor expansion valve is main throttling device. The high-pressure and high-temperature vapor refrigerant (point 2) discharged from the compressor passes through the 4-way valve, exchanges heat with the outside air in the outdoor heat exchanger and is condensed so as to be made into a condensed (point 3). The high-pressure two-phase refrigerant is somewhat reduced in pressure in the outdoor expansion valve and flows into the first indoor heat exchanger as an intermediate-pressure two-phase refrigerant (point 4). The intermediate-pressure two-phase refrigerant flowed into the first indoor heat exchanger exchanges heat with the indoor air, and is further condensed (point 5). The two-phase refrigerant ejected from the first heat exchanger flows into the indoor expansion valve. The refrigerant is reduced in pressure in the indoor expansion valve (point 6). The two-phase refrigerant flowing through the expansion valve makes noise like a "Jyuru-Jyuru"or"Poko-Poko". The low-pressure vapor refrigerant ejected from the second indoor heat exchanger returns to the compressor again through the 4-way valve (point 1). Since the indoor air is heated in the first indoor heat exchanger and cooled and dehumidified in the second indoor heat exchanger, it is possible to execute the dehumidification while preventing the reduction in the air temperature.

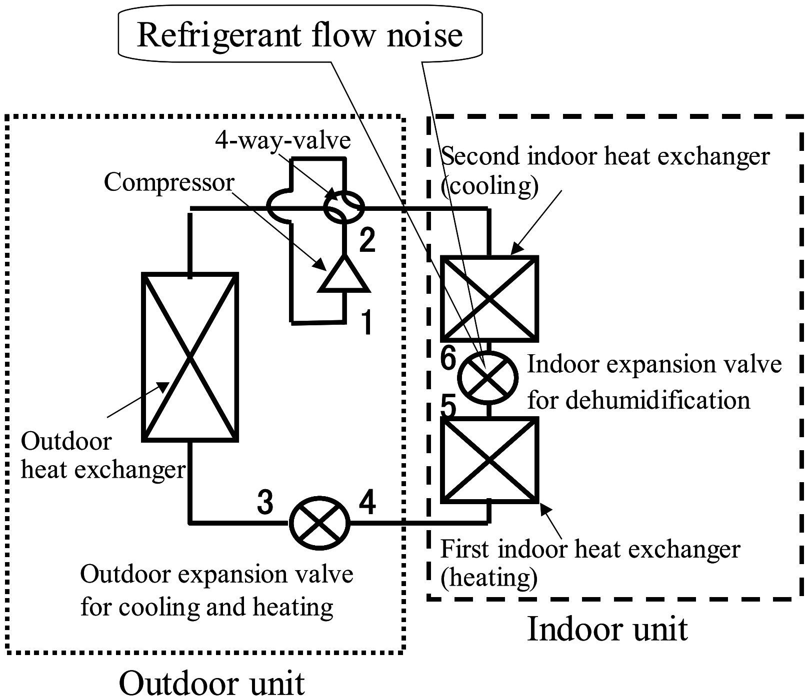

Figure 1: The refrigerant circuit diagram of the split type room air-conditioner with re-heat cycling dehumidification operation

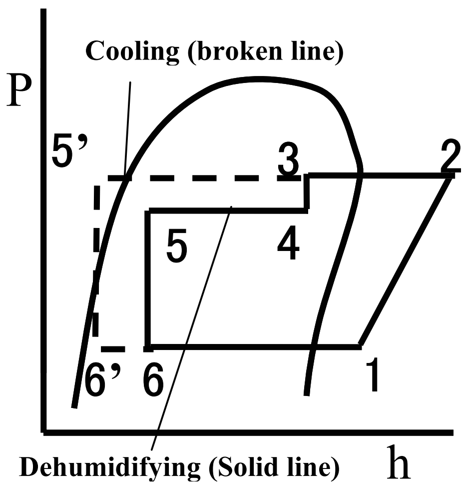

Figure 2: Pressure-enthalpy diagram

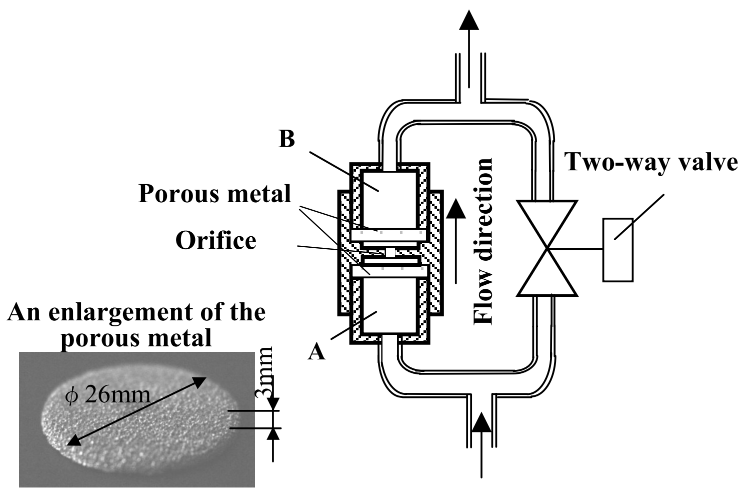

Figure 3: Sectional view of the new expansion valve for dehumidification with porous metal

3. NEW EXPANSION VALVE

Figure 3 shows the sectional view of the new indoor expansion valve. The new expansion valve consists of a two-way valve and an orifice with porous metal. In the expansion valve, a throttling process is composed of the orifice. In the cooling operation, the two-way valve is opened. In the dehumidifying operation the two-way valve is closed and the refrigerant is reduced in pressure in the orifice. Porous metals are disposed on the inlet side and the outlet side of the orifice. Spaces A and B obtaining a noise eliminating effect are disposed upstream of the inlet side porous metal and downstream of the outlet side porous metal. When two-phase refrigerant passes through an ordinary orifice, large refrigerant flow noise is produced inlet side and outlet side the orifice. In particular, when the two-phase refrigerant flows in a slug flow pattern, large refrigerant flow noise is produced upstream of the orifice. Using porous metal, two-phase refrigerant flow noise in the orifice can be greatly reduced.

4. EXPERIMENT

We visualized the test section of the orifice shown in Figure 4. The orifice diameter is 1mm and inner diameter of sight glass is 8mm. We recorded flow patterns using a high-speed camera (2000frame/sec), and observed the test section with or without porous metal in an anechoic box using experimental apparatus shown in Figure 5. Average hole's diameter of the porous metal is 0.5mm and thickness of it is 3mm and gap ratio is 96%.The experimental apparatus consists of an inverter driven compressor, a water-cooled condenser, an electrical heater controlled sub-cooling, a flow controller, a test section, and an electrical heated evaporator. The refrigerant mass flow rate is controlled by the rotational frequency of the compressor and measured by the mass flow meter located in the liquid line. The vapor quality at the inlet of the test section is calculated by temperature at the inlet of the flow controller, and is controlled by the electrical heater.

We measured noise level and pressure fluctuation in the orifice with or without porous metal using experimental apparatus. Background noise of the anechoic box is 20dB(A). The noise level is measured the position at 0.1m from center of the test section. Figure 6 shows sectional view of the orifice. It consists of an inlet pipe, an inlet space, an orifice, an outlet space and an outlet pipe. Figure 7 shows sectional view of the orifice with porous metal. It consists of an inlet pipe, an inlet space (space A), a porous metal, a mixing space, an orifice, a collecting space, a porous metal, an outlet space (space B) and an outlet pipe. The mass flow rate is changed from 26kg/h to 47kg/h, and the vapor quality is constant at 0.1 in this test. This experimental apparatus is installed R410A as a refrigerant. Inlet pressure of the test section is 2.4MPa.

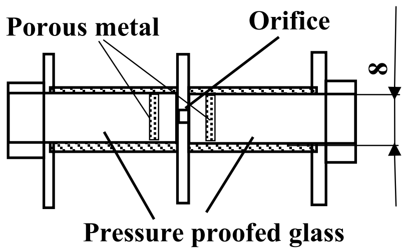

Figure 4:Visualized test orifice

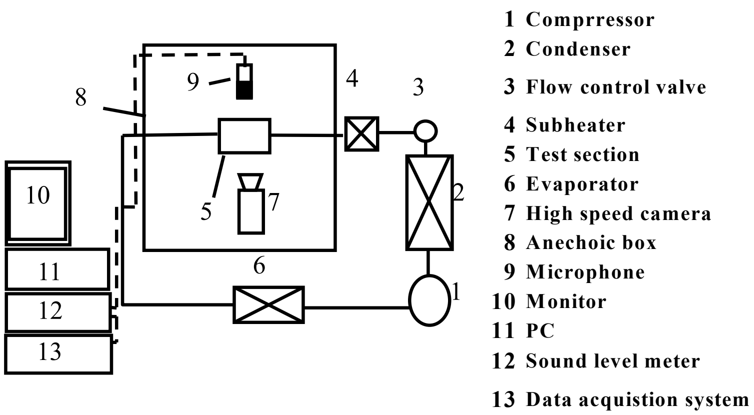

Figure 5:The experimental apparatus

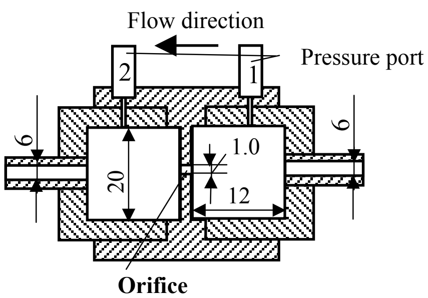

Figure 6:The orifice

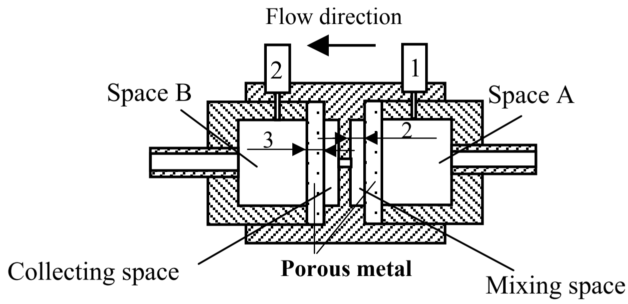

Figure 7:The orifice with porous metal

5. EXPERIMENTAL RESULTS

5.1 Flow Pattern

Figure 8 shows the upstream flow pattern of the orifice without porous metal. In this test, the mass flow rate is 35kg/h and the inlet vapor quality of the test section is 0.1. The flow pattern is slug flow. The slug flow is a vapor refrigerant intermittently flows in a flow direction. Figure 9 shows the upstream flow pattern of the orifice with porous metal. The slug in the refrigerant two-phase flow is divided into small bubbles through porous metal, and the flowing state of the refrigerant is made into uniform two-phase flow. Therefore sufficiently mixed two-phase refrigerant flows into the orifice. Figure 10 shows the downstream flow pattern of the orifice without porous metal. A refrigerant is made into a high-speed two-phase stream at an outlet. The flow pattern is turbulence and swirl. Figure 11 shows the downstream flow pattern of the orifice with porous metal. The flow speed of the refrigerant as a high-speed two-phase jet stream is sufficiently reduced by the outlet side porous metal.

5.2 Pressure Fluctuation

Figure 12 shows the pressure fluctuation of the upstream flow of the orifice without porous metal. Figure 13 shows the pressure fluctuation of the upstream flow of it with porous metal. In this test, the mass flow rate is 35kg/h and the inlet vapor quality of the test section is 0.1. The pressure fluctuation without porous metal is about ±2kPa, and irregular. When the vapor slug larger than an orifice passes through the throttle section, the vapor slug upstream of the orifice are broken and vibrated. Since a vapor refrigerant and liquid refrigerant alternately pass through the orifice, the speed of the refrigerant is fast when the vapor refrigerant passes and is slow when the liquid refrigerant passes. The pressure of the refrigerant upstream of the throttle section is fluctuated thereby. The pressure fluctuation of the upstream flow with porous metal is about ±0.5kPa. The two-phase refrigerant passes through the countless number of the fine vent holes of the inlet side porous metal. As a result, the vapor slugs are intermittently made into small bubbles. The flowing state of the refrigerant is made into a uniform two-phase flow. Accordingly, the vapor refrigerant and liquid refrigerant pass through the orifice at the same time, whereby the speed of the refrigerant is not fluctuated, and the pressure fluctuation is reduced.

Figure 14 shows pressure fluctuation of the downstream of the orifice without porous metal. Figure 15 shows pressure fluctuation of the downstream of it with porous metal. The pressure fluctuation of the downstream flow without porous metal is about ±1.5kPa, and also irregular. A refrigerant is made into a high-speed two-phase jet stream at an outlet and collides against an inner wall surface of the outlet pipe, whereby an orifice main body and an outlet flow path are vibrated all times and generated noise. In addition, large jet stream noise is produced by the turbulence and swirl generated by the high-speed two-phase jet stream at the outlet. Pressure fluctuation of the downstream flow with porous metal is about ±0.5kPa. The high-speed two-phase jet stream does not collide against an inner wall surface of the outlet pipe and no large swirl is produced in the stream, whereby jet stream pressure fluctuation is reduced.

5.3 Noise Level

Figure 16 shows the noise level induced in the orifice with or without porous metal. In this test the mass flow rate is changed from 27kg/h to 47kg/h and the inlet vapor quality of test section is 0.1. The noise level of the orifice without porous metal increase with increasing mass flow rate. The tone is intermittent like “Jyuru-Jyuru” or ”Poko-Poko” and is continuous and like “Shaa”. The noise level of the orifice with porous metal keeps constant at low level with increasing mass flow rate. The noise level of the orifice with porous metal is about 5dB(A) lower than the orifice without porous metal in this mass flow rate range. And the tone is only continuous and like “Shaa”.

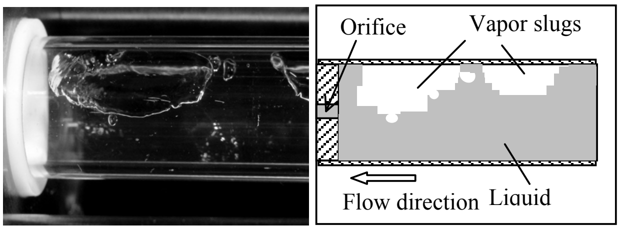

Figure 8:Inlet Flow Pattern without Porous Metal

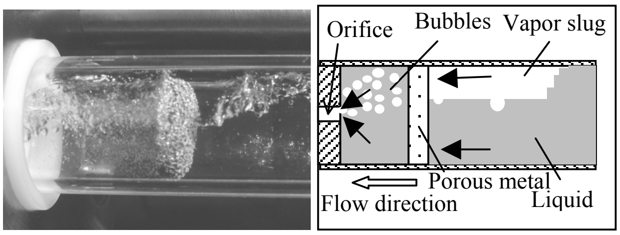

Figure 9: Inlet Flow Pattern with Porous Metal

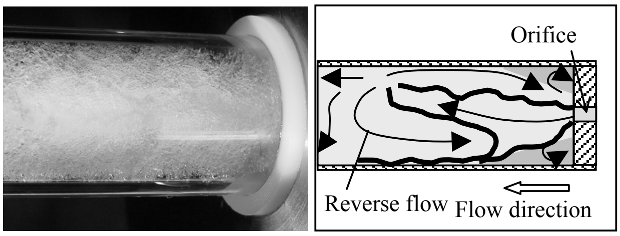

Figure 10: Outlet Flow Pattern without Porous Metal

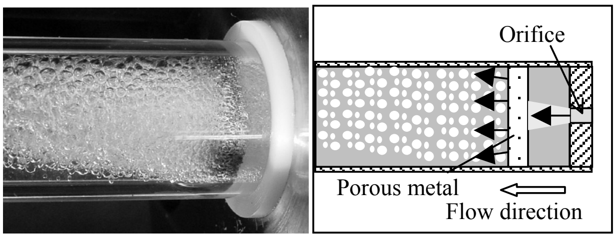

Figure 11: Outlet Flow Pattern with Porous Metal

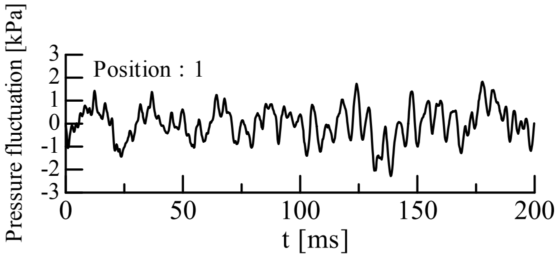

Figure 12: Inlet Pressure Fluctuation without Porous Metal

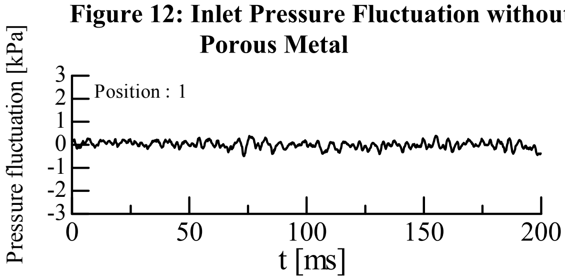

Figure13: Inlet Pressure Fluctuation with Porous Metal

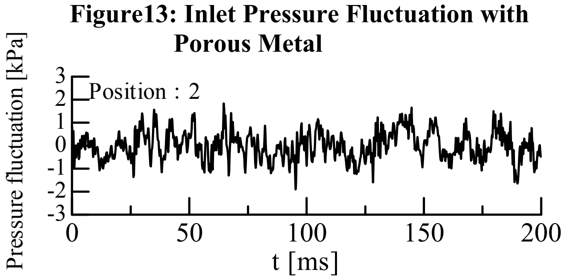

Figure 14: Outlet Pressure Fluctuation without Porous Metal

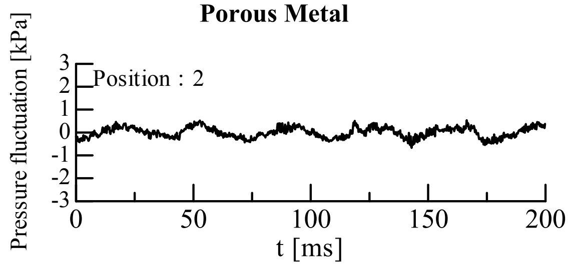

Figure 15: Outlet Pressure Fluctuation with Porous Metal

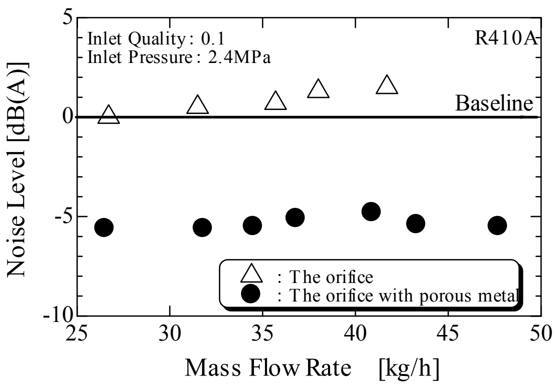

Figure 16: Noise level

6. UNIT PERFORMANCES

6.1 Testing Method and Conditions

The new expansion valve with porous metal is installed in the indoor unit in order to evaluate the improvement of the noise level in the re-heat cycling dehumidifying operation. The noise level of the indoor unit is measured in the anechoic room under 15 dB(A) background condition. And indoor air temperature is 297K with relative humidity 60%. And outdoor air temperature is 297K with relative humidity 80%. Measurement point of the noise level is set 1m front from center of the indoor unit and 1m below from there (JIS point).

6.2 Results

The mass flow rates are 34kg/h and 55 kg/h in this test. Figure 17 shows the noise level comparison of the ordinal expansion valve without porous metal and the new one. The noise level of the new expansion valve with porous metal is about 13dBA lower than the ordinal one. The tone of the ordinal expansion valve is intermittent like "Jyuru-Jyuru". Figure 18 shows the frequency characteristic comparison of the noise in the ordinal expansion valve and the new one. The noise level likely to hear for human from 0.5 kHz to 6 kHz of the new expansion valve is lower than the ordinal one.

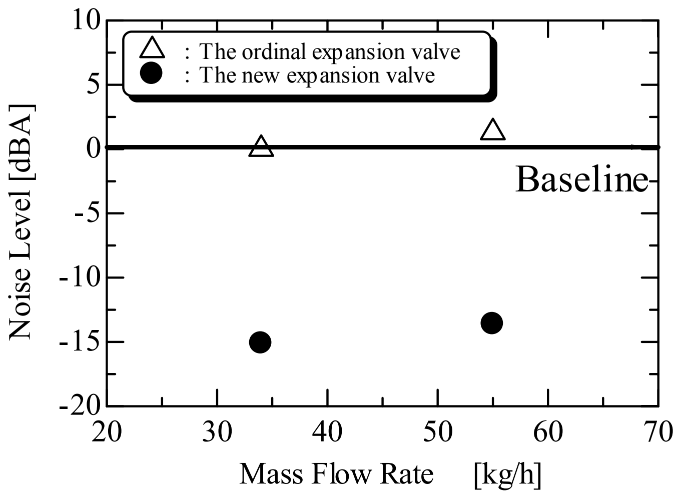

Figure 17: Noise level of the indoor unit

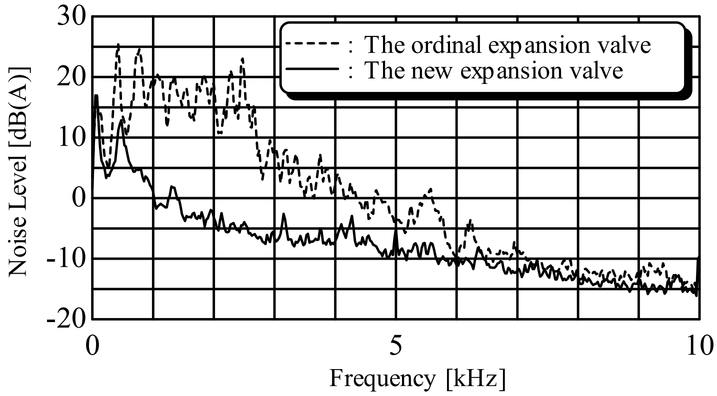

Figure 18: Frequency characteristic of the noise level

7. CONCLUSIONS

In order to reduce the noise level of the expansion valve installed into the indoor unit with the re-heat refrigerant cycling system , we have developed a new type of the expansion valve with porous metal disposed both sides of the orifice.

(1)Since porous metals arranged as the porous permeable members are disposed on the inlet side and outlet side of the orifice, the flowing state of the refrigerant is made into the uniform at the downstream flow of the porous metal.

(2)The pressure fluctuations in the orifice with porous metal are from one forth to one third compared to those of it without porous metal.

(3) The noise level of the new expansion valve with porous metal is about 5dBA lower than ordinal one without porous metal.

(4) The noise level of the indoor unit installed the new expansion valve with porous metal is about 13dBA lower than ordinal one without porous metal.

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