Diffluence Characteristics Investigation of Distributors Used in Heat Pump Type Air Conditioner with Microgroove Tubes

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Abstract: Well design and application of a distributor is important to obtain a reasonable distribution of refrigeration flow among the multi paths of a heat exchanger in heat pump type air conditioner. In this paper, theoretical and experimental studies on the diffluence characteristics of distributors used in heat pump type air conditioners with microgroove tubes were done. The main factors influencing diffluence performance of distributors were summarized by theoretical analysis. The effects of the main factors on diffluence performance of typical distributors were investigated by experiments with air and water as the working fluid instead of actual refrigerants. Based on the theoretical analysis and experimental results, improvement methods for the existing distributors were proposed, and the improvement effects were verified by experiments.

Key Words: air conditioner, diffluence, distributor, heat hump, microgroove tube

1 INTRODUCTION

Adopting heat exchangers with microgroove tubes (tube diameter is smaller than or equal to 5 mm) may reduce refrigerant charge in air conditioners effectively (Wu et al. 2012), and can promote the safety of applying environment-friendly but inflammable refrigerants, e.g. R290 (Ding et al. 2012). However, the application of microgroove tubes makes the pressure drop on the refrigerant side increase sharply. In order to avoid the performance degradation resulted from the pressure drop increasing, refrigerant flow paths should be increased. The increase of refrigerant flow paths enlarges the risk of uneven distribution of two phase refrigerant among different paths, which makes the heat transfer area of heat exchangers not be fully used. Therefore, distributors are widely used in heat pumps to ensure a reasonable distribution of refrigerant among different paths.

A distributor used for multicircuit evaporators usually consists of a mixing cavity and several dividing branches (Nakayama et al. 2000). It is fastened to the outlet of the expansion valve. The diffluence performance of distributors has a direct effect on the refrigerant flow rate entering into each individual evaporator circuit. If the distributor could not divide the refrigerant well distributed to each circuit, the heat transfer area in some circuits cannot be fully used. In the path obtaining fewer refrigerant flow rate from the distributor, the refrigerant will be obviously overheated; while in the path obtaining excessive refrigerant flow rate, the refrigerant cannot evaporate completely, leading to the risk of damage to the compressor. Thus, the performance of evaporator as well as the performance of air conditioner will degrade (Wen et al. 2008). Therefore, it is necessary to study the diffluence characteristics of distributors.

Some scholars had realized the importance of distributors to the heat exchanger performance. Muller and Chiou (Mueller and Chiou 1988) reviewed various types of distributors firstly. Kitto and Robertson (Kitto and Robertson 1989) studied effects of maldistribution of flow on heat transfer equipment performance. Horiki and Osakabe (Horiki and Osakabe 1999) did experimental investigation of a horizontal manifold with four vertically branches with air and water as the experimental medium, and analyzed effect of protruding length on the distribution. Zhang et al. (Zhang et al. 2004) and Jiao and Baek (Jiao and Baek 2005) studied the effects of different distributor configurations on the flow distributor in plate-fin exchangers. The results show that, the main influence factors for the diffluence performance of distributors are the distributor configuration and Reynolds number; the performance of the distributor was improved by adding a fluid complementary cavity. Lee and Lee (Lee and Lee 2004) performed the distribution of two-phase annular flow at header-channel junctions simulating the corresponding parts of compact heat exchangers with air and water as the experimental medium, and analyzed the effects of mass quality at the inlet of the vertical header and the intrusion depth of the horizontal channels into the header wall on diffluence performance. The results show that, less amount of liquid was separated out though the channels at the rear part with zero intrusion-depth, which was reversed at the rear part with the deeper intrusion; a uniform liquid-flow distribution could be achieved simply by adjusting the intrusion depth. Webb and Chung (Webb and Chung 2005) found that the header orientation and the branch number have a great effect on diffluence performance of distributors.

In this study, the main factors influencing diffluence performance of distributors used in heat pump type air conditioner with microgroove tubes were analyzed, the effects of the main factors on performance of typical distributors were investigated, and then the improvement ways for the distributor structures were proposed.

2 FACTORS ANALYSIS

2.1 Research Objects

The distributor is used on multicircuit evaporators. It is fastened to the outlet of the expansion valve, as shown in Figure 1. It distributes the refrigerant to each individual evaporator circuit.

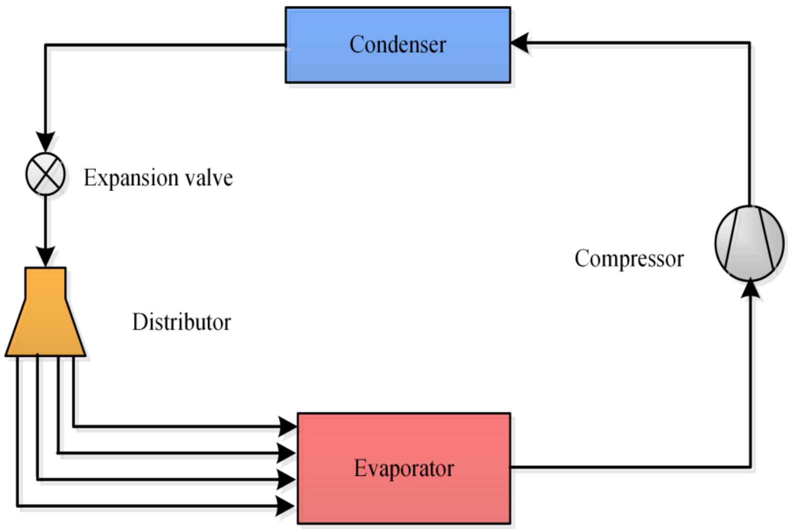
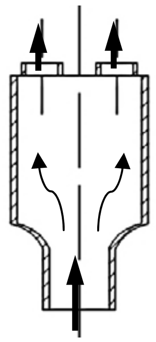
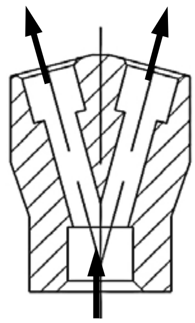
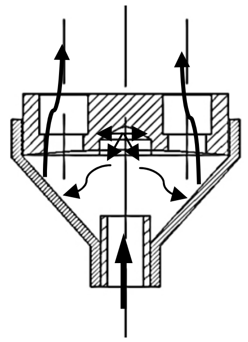


Figure 1: The Installed Location of A Distributor

Table 1: Schematic Diagrams of Three Types of Distributors

Jack-type distributor	Cone-type distributor	Reflection-type distributor
		

2.2 Theoretical Analysis

The factors influencing diffluence performance of distributors can be divided into two parts: 1) internal factors, such as the flow path pattern of a distributor, the cross-section area of the mixing cavity and the internal surface roughness of a distributor; 2) external factors, such as the installation angle, the refrigerant flow rate, the dryness of refrigerant and the viscosity of refrigerant.

Among the above influencing factors, the internal surface roughness of a distributor and the viscosity of refrigerant will not be analyzed because they are only related to a certain distributor and a certain kind of refrigerant; the other factors will be analyzed experimentally

2.2.1 Flow path pattern

There are two forms of flow path patterns: 1) sudden expansion and sudden contraction; 2) gradual expansion and gradual contraction. Both forms of the flow path pattern make two-phase refrigerant mixed by increasing its velocity through reducing its pressure. However, the results are different when the forms of flow path pattern are different. Thus, the flow path pattern is one of the main factors influencing distributors' performance.

2.2.2 Cross-section area of the mixing cavity

Two-phase flow is regarded to be single-phase flow when its flow pattern is mist flow, meaning the gas phase and liquid phase are fully mixed. Mist flow pattern in the distributor is preferred to guarantee the refrigerant is equally distributed. The flow pattern can be determined according to Weisman Equation (Weisman 1975), as shown in Equation (1). When the apparent liquid mass flow rate (G_l) is larger than 10^7 kg·m^{-2}·h^{-1}, the two-phase refrigerant is the mist flow patter.

$$G_l = m \cdot (1 - x) / A \qquad (1)$$

where, G_l is the apparent liquid mass flow rate (kg·m^{-2}·h^{-1}), m is the mass flow rate (kg·h^{-1}), x is the dryness of refrigerant, A is the cross-section area of the mixing cavity (m^2).

Therefore, it is easier to reach mist flow with smaller cross-section area of the mixing cavity. Thus, the cross-section area of the mixing cavity is one of the main factors influencing distributors' performance.

2.2.3 Installation angle

In actually application, distributors may not be always installed vertically because of the limitation of space and installation precision. When distributors are obliquely installed, the flow rate of liquid phase will increase in the outlet, which is closer to the ground because of gravity, resulting in uneven distribution. Therefore, the installation angle is one of the main factors influencing distributors' performance.

2.2.4 Dryness and flow rate of refrigerant

The flow pattern reflects the existing form of liquid phase and gas phase of two-phase flow fluid. Mist flow means the two phases are fully mixed. Flow pattern is identified by flow rate and dryness of two-phase flow. For the dryness of refrigerant in air conditioner is between 0.18 and 0.23, and the flow pattern in such a small variation range has almost not affected by the dryness. Therefore, only the flow rate is important on the distributors' performance.

2.2.5 Determination of main factors

The main factors influencing distributors' performance are the flow path pattern, the cross-section area of the mixing cavity, the installation angle and the refrigerant flow rate.

3 EXPERIMENTAL APPARATUS

3.1 Experimental Principle

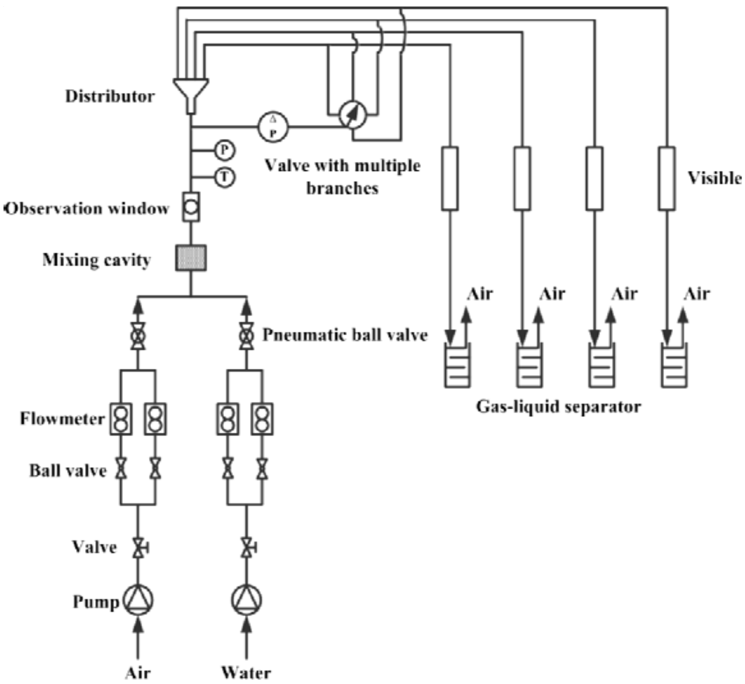


Figure 2: Schematic Diagram of Experimental System

Air and water are adopted as the experimental medium in this study. The experimental rig is an open system as shown in Figure 2. It mainly includes a water pump (1ZDB-35, $1m^3 \cdot h^{-1}$), an air pump (V-0.17/7, 0.17 $m^3 \cdot h^{-1}$), a mixing cavity, a valve of with multiple branches, two fluid volume flowmeters (LZM-15ZT, ±4%), two gas volume flowmeters (LZM-6T, ±4%), an electronic scale (G&G –TC10kg, 0.0001kg), a differential pressure sensor, and a data acquisition instrument.

Air and water are pumped into the system by an air pump and a water pump respectively and mixed in a mixing cavity. The flow rates of air and water are controlled by valves and measured by a fluid volume flowmeter and a gas volume flowmeter respectively; and then the two-phase flow is distributed into each outlet. The pressure differential of distributor's inlet and outlet is measured by a differential pressure sensor. The flow patterns of inlet and outlets can be viewed through observation windows. Air and water are separated by going through a gas-liquid separator, letting water stays in separators. The distributors' performance is valued by measuring water qualities in separators.

3.2 Experimental Objects

The experimental objects are shown in Table 2: a jack-type distributor with 4 branches, two cone-type distributors with 4 and 6 branches respectively, two reflection-type distributors with 4 and 6 branches.

Table 2: Schematic Diagram of Experimental Objects

Jack-type distributor	Cone-type distributor		Reflection-distributor	
	4 branches	6 branches	4 branches	6 branches
				

3.3 Experimental Conditions

In the experiment, the flow rates of air and water are determined according to R290 heat pump type air conditioner with 2600W capacity under standard cooling and heating conditions. The air velocity is the same as that of R290 gas phase, the water velocity is the same as that of R290 liquid phase and the void fraction maintains the same. In order to study how the variation of flow rates influence the diffluence performance, 1.5 times of the air/water flow rates under standard conditions are added. Therefore, the air/water flow rates are: 8.7L·min^{-1}/0.73 L·min^{-1}, 8.7L·min^{-1}/0.93 L·min^{-1}, 13.1L·min^{-1}/1.1 L·min^{-1} and 13.1L·min^{-1}/1.4 L·min^{-1}.

In the actual installation, distributors usually cannot be vertically installed because of the space limitation. Giving consideration of the most extreme installation—horizontally installed (installation angle is 90°) , the installation angles are determined as 0°, 10°, 15°, 30°, 60°, 90°, as shown in Figure 3.

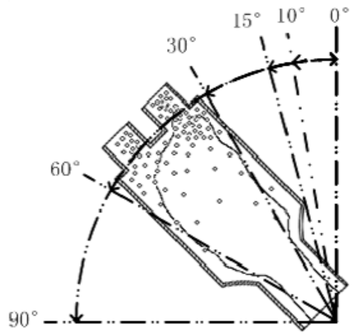


Figure 3: Installation Angles

According to flow rates and installation angles, the experimental conditions are shown in Table 3.

Table 3: Experimental Conditions

Evaporating temperature (°C)	Air/water flow rate (L·min-1/ L·min-1)	Installation angle (°)					
2	8.7/0.73	0	10	15	30	60	90
	13.1/1.1	0	10	15	30	60	90
10	8.7/0.93	0	10	15	30	60	90
	13.1/1.4	0	10	15	30	60	90

4 EXPERIMENTAL RESULTS

4.1 Data Reduction

The sample variance is used to evaluate the performance of distributors. The diffluence performance is better as the sample variance is smaller. The sample variance is calculated by Equation (2):

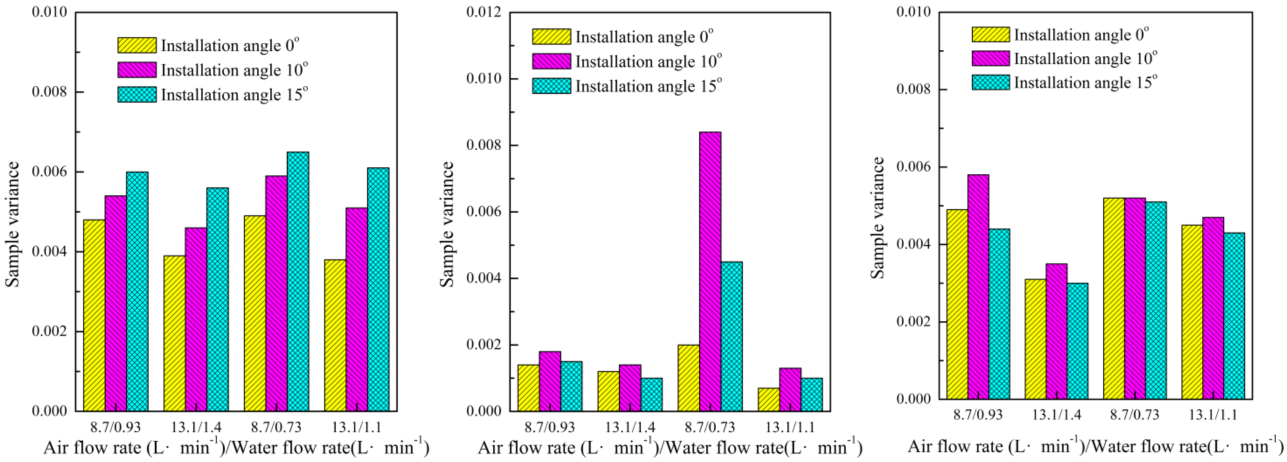
$$S^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(\frac{m_i - m_{ave}}{m_{ave}}\right)^2 \qquad (2)$$

where, S is the sample variance, n is the number of experiments, m_i is the water quality of branch i (kg), m_{ave} is the average water quality (kg).

4.2 Influence of Flow Rate

The water qualities of each outlet of a jack-type distributor with 4 outlets, a cone-type distributor with 6 outlets and a reflection-type distributor with 6 outlets were measured under the conditions with the air/water volume flow rates of 8.7L·min^{-1}/0.93 L·min^{-1}, 13.1L·min^{-1}/1.4 L·min^{-1}, 8.7L·min^{-1}/0.73 L·min^{-1}, 13.1L·min^{-1}/1.1 L·min^{-1}, and installation angles of 0°-15°.

The sample variances of Jack-type distributor, Cone-type distributor with 6 branches and Reflection-type distributor with 6 branches under different air/water flow rates with installation angles of 0°-15° are shown in Figure 4(a), (b), (c), respectively.



(a) Jack-type **(b) Cone-type** **(c) Reflection-type**

Figure 4: Results of Different Distributors with Different Flow Rates

Figure 4(a) shows, when the air/water flow rate increases, the sample variance becomes smaller, meaning that the diffluence performance of Jack-type distributor gets better as flow rate increases.

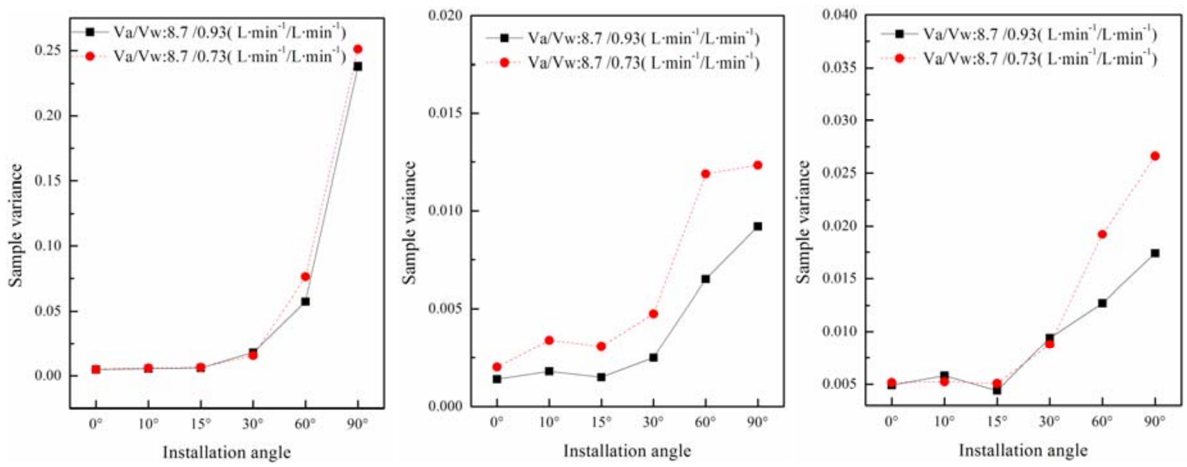
Figure 4(b) shows, when the air/water flow rate increases, the sample variance becomes smaller, meaning that the diffluence performance of Cone-type distributor gets better as flow rate increases.

Figure 4(c) shows, when the air/water flow rate increases, the sample variance becomes smaller, meaning that the diffluence performance of Reflection-type distributor gets better as flow rate increases.

4.3 Influence of Installation Angle

The water qualities of each outlet of a jack-type distributor with 4 outlets, a Cone-type distributor with 6 outlets and a Reflection-type distributor with 6 outlets were measured under conditions with the air/water flow rates of 8.7L·min^{-1}/0.93 L·min^{-1} and 8.7L·min^{-1}/0.73 L·min^{-1}, and installation angles of 0°-90°.

The sample variances of Jack-type distributor, Cone-type distributor with 6 branches and Reflection-type distributor with 6 branches under different installation angles with air/water flow rates of 8.7L·min^{-1}/0.93 L·min^{-1} and 8.7L·min^{-1}/0.73 L·min^{-1} are shown in Figure 5 (a), (b), (c) respectively.



(a) Jack-type **(b) Cone-type** **(c) Reflection-type**

Figure 5: Results of Different Distributors under Different Installation Angles

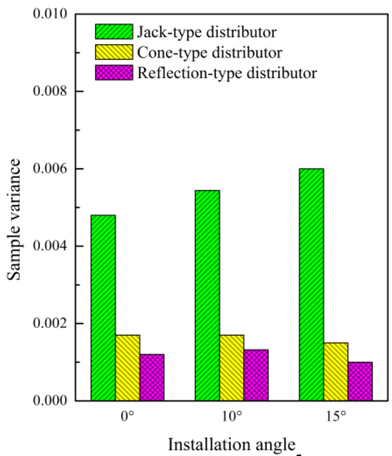
Figure 5(a) shows, when the installation angle increases, the sample variance becomes larger, meaning that the diffluence performance of Jack-type distributor gets worse as installation angle increases. Therefore, Jack-type distributor should be vertically installed.

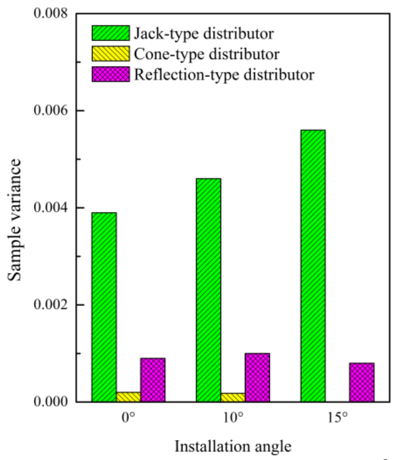
Figure 5(b) shows, when the installation angle is larger than 30°, the diffluence performance degrades as installation angel increases. Therefore, Cone-type distributor is suitable to be installed with the inclination angle from 0°-30°.

Figure 5(c) shows, when the installation angle is between 0° and 15°, the diffluence performance is good; when the installation angle is larger than 15°, the diffluence performance degrades as installation angel increases. Therefore, Reflection-type distributor is suitable to be installed with the inclination angle from 0°-15°.

Influence of Configuration

A Jack-type with 4 branches, a Cone-type distributor with 4 branches and a Reflection-type distributor with 4 branches were chosen to be tested to study the influence of distributor configurations. The water quality of each branch was measured under conditions with the air/water flow rates of 8.7L·min^{-1}/0.93 L·min^{-1} and 13.1L·min^{-1}/1.4 L·min^{-1}, installation angles of 0°-15°, The samples variances under different air/water flow rates are shown in Figure 6 (a) and (b) respectively.





(a) Air/water flow rate of 8.7L·min^{-1}/0.93 L·min^{-1} **(b) Air/water flow rate of 13.1L·min^{-1}/1.4 L·min^{-1}**

Figure 6: Results with Different Distributors under Different Air/water Flow Rates

According to Figure 6 (a), the sample variance of Jack-type distributor is the largest, followed by those of Reflection-type distributor and Cone-type distributor orderly under the air/water flow rate of 8.7L·min^{-1}/0.93 L·min^{-1} with installation angles of 0°-15°. The diffluence performance of Cone-type distributor is the best, followed by Reflection-type distributor and Jack-type distributor under above conditions.

According to Figure 6 (b), the sample variance of Jack-type distributor is the largest, followed by those of Cone-type distributor and Reflection-type distributor orderly under the air/water flow rate of 13.1L·min^{-1}/1.4 L·min^{-1} with installation angles of 0°-15°. The diffluence performance of Reflection-type distributor is the best, followed by Cone-type distributor and Jack-type distributor under above conditions.

According to Figure 6, Reflection-type distributor has the most stable performance, while Jack-type distributor has the worst performance under two different air/water flow rates with different installation angles.

4.4 Diffluence Characteristics of Distributors

- Jack-type distributor

Installation angle has the largest effect on the diffluence performance of Jack-type distributor. It should be installed vertically. The diffluence performance becomes better as flow rate increases. The integrated performance is the worst in consideration of the performance with different flow rates and installation angles.

- Cone-type distributor

Installation angle has the least effect on the diffluence performance of Cone-type distributor. It can perform well when the installation angle is between 0° and 30°. The diffluence performance gets better as flow rate increases. The integrated performance is in the middle in consideration of the performance with different flow rates and installation angles.

- Reflection-type distributor

Installation angle has less effect on the diffluence performance of Reflection-type distributor. It can perform well when the installation angle is between 0° and 15°. The diffluence performance gets better as flow rate increases. The integrated performance is in the best in consideration of the performance with different flow rates and installation angles.

5 DIRECTIONS OF STRUTURE IMPROVEMENT

According to the related knowledge of two-phase flow and the experimental results, the directions of structure improvement are: 1) Make the flow path smooth to guarantee the inertia force is big enough to overcome gravity; 2) Make cross-section area of mixing cavity small to contribute to the formation of mist flow.

According to the directions of structure improvement, the flow path pattern form of Jack-type distributor was improved to be gradual expansion from sudden expansion. The improvement is shown in Figure 7.

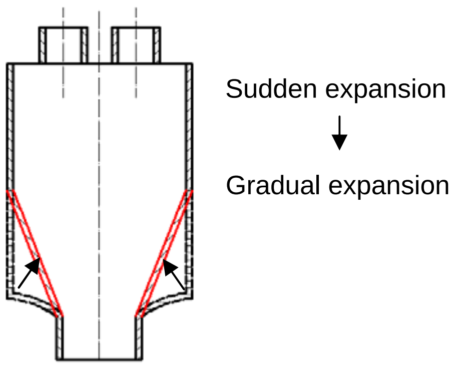


Figure 7: Structure Improvement of Jack-type distributor

If there's no machining error, the fluid can be divided equally when the distributor is vertically installed. In order to avoid the influence of machining error, the ratios of the sample variances under different installation angles to the sample variance under the installation angle with 0° are defined to compare the diffluence performances of original distributors and improved distributors. The variance samples of original and improved distributors under installation angle of 0^o are shown in Table 4. The comparing results under the evaporation temperature of 10˚C with different installation angles are shown in Figure 8.

Table 4: Variance Samples of Original and Improved Distributors under Installation Angle of 0^o

Air flow rate/water flow rate ($L{\cdot}min^{-1}$/ $L{\cdot}min^{-1}$)	Jack-type	
	Original	Improved
8.7/0.93	0.0048	0.0045
13.1/1.4	0.0039	0.0031

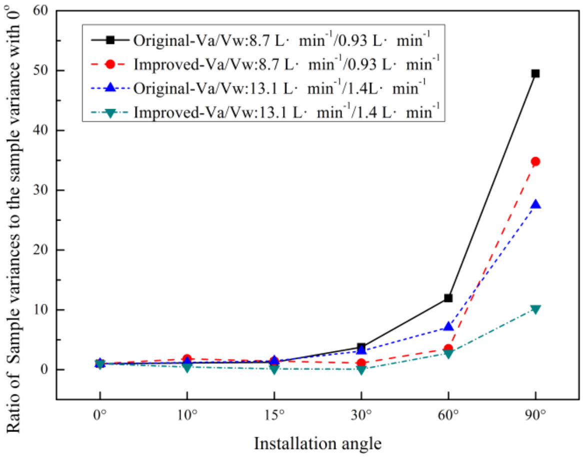


Figure 8: Sample Variance Ratios of Original and Improved Jack-type Distributor Varies as The Function of Installation Angle

According to Table 4 and Figure 8, the influences of the flow rate and the installation angle on the improved distributors are less than those on the original distributor, meaning that the improved distributors have more stable diffluence performance. Therefore, the directions of structure improvement are correct.

6 CONCLUSIONS

1) The main factors influencing distributors' performance include the flow path pattern, the cross-section area of the mixing cavity, the installation angle and the refrigerant flow rate.

2) The diffluence characteristics of the three typical types of distributors were obtained. Installation angle has the largest effect on the diffluence performance of Jack-type distributor, followed by Reflection-type distributor and Cone-type distributor. Jack-type distributor should be installed vertically; Reflection-type can perform well when the installation angle is between 0° and 15°; Cone-type distributor can perform well when the installation angle is between 0° and 30°. All distributors perform better as the flow rate increases. Taking the influences of flow rates and installation angles into consideration, the integrated performance of Reflection-type distributor is the best, followed by Cone-type distributor and Jack-type distributor.

3) The directions of structure improvement were obtained. The directions of structure improvement are: 1) make the flow path smooth to guarantee the inertia force is big enough to overcome gravity; 2) make cross-section area of mixing cavity small to promote the formation of mist flow.

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