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Analysis of Indoor Environment Safety with R32 Leaking From a Running Air Conditioner

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Abstract

This paper, in the view of indoor security, analyzes the leak variation and indoor R32 concentration distribution when it leaks from the running indoor unit using experimental methods. The results show that the leak rate of R32 decreases with the air conditioner operating. And the leak process of refrigerant under operating conditions can be classified into two stages, fast leak stage and slow leak stage. The concentration of test points increases at first, then decreases and gradually stabilizes. Near the leak hole, it is the highest and varies dramatically. And it is high in the supply air mine stream, but it is only about 15% of the LFL. The concentration of the corner that the supply air cannot reached is the lowest. The indoor security during the leaking process of R32 is evaluated, and the results show that the combustible zone only appears near the leak hole, and its duration is very short. Ignition experiment is took in the combustible region and the results show that the candle flame and spark diffuse slightly, but it cannot spread effectively. It can be concluded that the hazard of using R32 as the refrigerant of air conditioner is low with the air velocity and angle keeping at 5.8m/s and 25° . In order to improve the security of the indoor environment further, the paper also analysis the impact of exhaust on indoor R32 concentration distribution and the results indicate that ventilation can reduce the indoor R32concentrationeffectively. Thus, it can reduce the risk of fire by opening the exhaust fan when R32 leaks with the air conditioner running.

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Keywords: R32, leak, diffusion, security, exhaust

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1. Introduction

With the increasing of environmental problems, general refrigerants like CFCs and HCFCs are all forbidden. In order to reduce the adverse effect to the atmospheric environment, searching for green alternative refrigerants with good thermal performance is urgent. Alternative refrigerant for R22 include R410A、R290、R32、R407C、R125 and R1234yf, etc. Though their COP are all lower than R22, R32 has some advantages. The Ozone Depletion Potential (ODP) of R32 is 0 and the Global Warming Potential (GWP) is only one third of R410A [1,2,3]. In addition, the cooling capacity per unit volume of R32 is higher than that of R22. With the same cooling capacity, the charge amount of R32 is only 57% of R22. With good thermal performance and environmental characteristics, R32 has become a highly promising alternative refrigerant, but the application is limited by its flammability. Thus it's significant to analyze the indoor environment safety with R32 leaking.

The researches at home and aboard on the diffusion of the flammable refrigerant leak can be concluded as follows:

The impact of leak rate and the position of leak hole on the concentration distribution was analyzed using experimental methods [4,5]. When the leak rate is bigger than 800g·min-1, there will be some high concentration area that may cause dangers [6]. The leaked refrigerant gathers near the floor and the upper part of the room will be safe when refrigerant leaks from a cabinet air conditioner. And refrigerant concentration in the middle part of the room is the lowest when the refrigerant leaks from a wall-mounted air conditioner [7].The indoor safety was tested when flammable refrigerant leaked from air conditioners under operating conditions. The combustible zone appeared near the leak hole and it was very small when the leak rate kept constant [8].

A quantitative risk assessment (QRA) model was introduced to evaluate the possibility of fire when hydrocarbon refrigerants in the storages and equipment [9,10].The explosion hazard of flammable refrigerant leakage was evaluated and the results show that the dangerous level of using flammable refrigerant in small size air conditioner is low, but it's possible to cause fire if there are some effective fire sources[11,12]. Research on the leakage of R290 shows that when refrigerant's leak causes fire, it's dangerous to human's health when the fire burns the outdoor unit shell and causes a heavily smoke. The ignition characteristics of R32 was analyzed, and the results show that R32 can only be ignited by open flame of pilot burner with LPG supply [13]. The distribution of R32 concentration near the floor is lower than the Lower Flammability Limit (LFL) when a wall-mounted air conditioner leaks. However, the distribution of concentration near the floor is higher than the Upper Flammability Limit (UFL) when the refrigerant leak from a cabinet air conditioner [14]. The influence of leak rate, fresh air flow and exhaust position on indoor R29 concentration distribution and security was analyzed, and it can be concluded that the exhaust fan should be located at lower part of the room to exhaust the heavy gas effectively [15,16,17].

In summary, most of the papers studied the leak of flammable refrigerant at a constant leak rate using simulation methods, which is different from leak with the air conditioner operating. This paper studies the leak and diffusion of R32 with the air conditioner running which is important for indoor safety and accident prevention when using R32 as the refrigerant of air conditioner.

2. Experimental device and contents

2.1 Experimental Device

In this study, R32 leaked from a wall-mounted air conditioner which is installed at the height of 2.2m in a room 3.9×2.9×2.75m3. According to Tianjin meteorological parameters, the air conditioner was selected to meet the demand. The characteristic parameters of the conditioner are shown in Table1. Indoor unit and outdoor unit were fixed by a Z-shaped bracket and the bracket was placed on an electronic balance. Usually, refrigerant leaks at the inlet or the outlet of the evaporator. And it is generally slit leak or hole leak. This paper studied the hole leak of R32 at the outlet of the evaporator with the supply air velocity and angle keeping at 5.8m/s and 25° . The supply air angle was showed in Figure1. In this experiment, the diameter of the leak hole is 5mm and maintaining the valve at 1/8 of fully opened. The position of the leak hole is shown in Figure 1. Other equipment and instruments used in experiment are shown in Table 1.

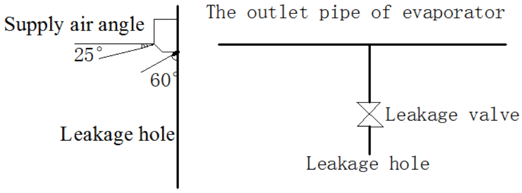

Fig. 1. Define of air supply angle and position of leak hole

Table 1. Equipment and instrument parameters

Name	Models	Capacity and accuracy
Air conditioner	LS-3541AT	Cooling capacity：3500W Circulating flow：600m3/h
Concentration detector	QD6310	±5%FS, 0~100%VOL
Electronic Balance	WT1503L	1g, 0~150kg
Anemometer	Swema Air 40	±0.04m/s

2.2 Experimental Contents

In order to explore the leakage and diffusion variation of R32, the mass change and indoor concentration distribution of R32 should be measured. In the experiment, the electric balance was used to measure the change of refrigerant mass. Concentration detectors located at six measuring points (Fig. 2) were used to analyze the concentration distribution of R32 in the room.

The experiment procedure was as follows. First, charge refrigerant and keep the amount of charging at 780g± 70g. Second, adjust the air conditioning state to experimental conditions and maintain the state about 30mins to make a stable flow field. Third, open the leak hole and keep the conditioner working for 1.5h. Finally, open the exhaust fan when R32 and the indoor air were fully mixed.

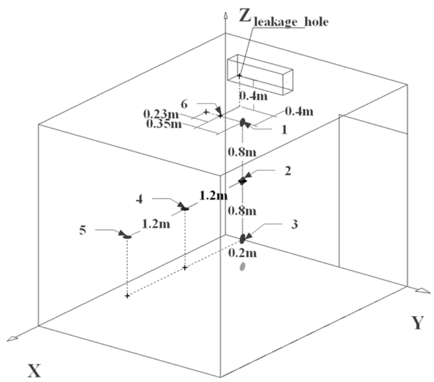

Fig. 2. Experimental equipment and test points

3. Results and discussion

3.1 The Leak variation of R32 with the air conditioner operating.

The mass variation of R32 is shown in Fig. 3 with the air velocity and angle keeping at 5.8m/s and 25° . The results show that the refrigerant leak procedure with the air conditioner operating can be classified into two stages, fast leak stage and slow leak stage. In the fast leak stage, 80% of R32 was leaked within 8mins and the leak rate is about 71.1 g/min. In the slow leak stage, the leak rate is about 6.52g/min. It is due that the pressure at the leak hole is high at the beginning and the compressor replenishes the pressure at the leak hole continuously. With the leakage of R32, the pressure at leak hole and the leak rate decreases. The leakage of R32 is finished when the pressure at the leak hole is equal to the ambient pressure.

It can be found that the leak rate of R32 under conditioning condition is not a constant value. The leak procedure with the air conditioner running can be classified into fast leak stage and slow leak stage.

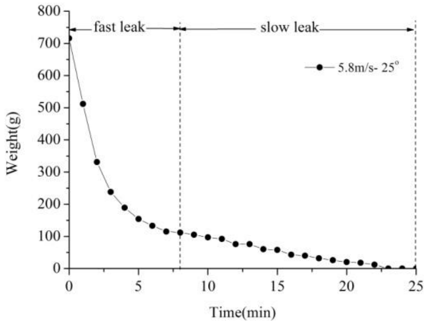

Fig. 3. R32 leak variation with air conditioner operating

3.2 Indoor Concentration Distribution of R32

Indoor R32concentration distribution was measured with the air velocity and angle keeping at 5.8m/s and 25° . According to the results above, it can be found that the leakage of R32 finished within 25mins. Therefore, the diffusion of R32 can be clarified into leak with diffusion stage and convective diffusion stage. This paper analyzes the concentration variation at six typical points. Point6 was located at the opposite of the leak hole. Point1 to point 3 were located at the plane of X=0.4m. Point 4 and point5 were located at the plane of Z=1.0m (Fig. 2).

The results described in Fig. 4 show the concentration variation of point6. First, it increases quickly in leak with diffusion stage. With decreasing of the leak rate and the interaction of turbulence air flow, the concentration of point6 decreases and gradually stabilizes. Concentration values of each point at typical times are shown in Table2. The concentration of point6 which was located at the opposite of the leak hole, exceeds the LFL at 77s and the maximum concentration is about 119.7%of the LFL. It keeps in the flammable range for 26s. Therefore it is a dangerous area. In the convective diffusion stage, due to the convection of supply air the concentration decreases gradually. And it was only 0.86vol% at the end of convective stage.

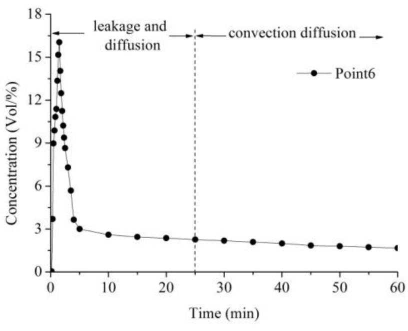

Fig. 4. Concentration variation of point6

Table 2. Concentration values of typical time

Point	C_{max}/vol%	C_{end}/vol%	ΔC/vol%
1	2.62	1.26	51.9%
2	1.68	0.86	48.8%
3	2.91	1.31	54.9%
4	3.09	1.44	53.4%
5	2.58	1.26	51.1%
6	16.76	0.86	94.9%

The concentration distribution at plane of X=0.4m is described in Fig. 5. The results described in Fig. 5. and Table2 show that the maximum concentration of point2, point3 and point1 are 12.0%, 20.8% and 18.7% of the LFL respectively. The maximum concentration of point3 is about 10.1% higher than that of point1 due to the combined effect of air flow and sedimentation of R32. In the convective diffusion stage, the concentration of each point and the concentration difference between different points decreases gradually. At the end of convective diffusion stage, the concentration of each point is about 51.9% lower than its maximum concentration due to the effect of supplied air convection. At the end of the convective diffusion stage, the concentration difference between point3 and point1 is decreased to 4.1%.

The results described in Fig. 6 and Table2 show that the maximum concentration of point 2 is lower than that of point4 and point5. The maximum concentration of point4 and point5 is about 3.09vol% (22.1%of the LFL) and 2.58vol% (18.4% of the LFL). The concentration of point 4 is about 17.6% higher than that of point5. It is because that the concentration of R32 decreases along the jet due to the entering of air along the jet and the bending of jet. With the convection of supply air the concentration of each point decreased gradually. At the end of convective diffusion stage, the concentration of each point is about 51.1% lower than its maximum concentration respectively. And the concentration difference between point4 and point5 is about 9.4% that's because point4 was located at the mainstream of the air supply and the significant effect of convective.

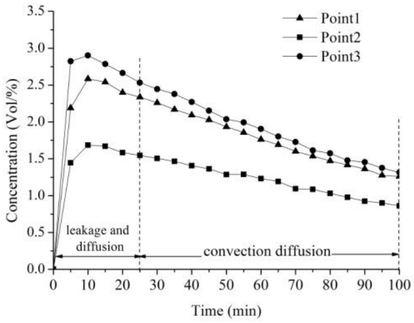

Fig. 5. Concentration variation of plane X=0.4m

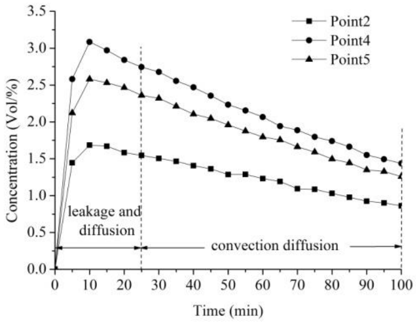

Fig. 6. Concentration variation of plane Y=1.0m

In summary, the concentration variation trend of points are the same. It increased at first then decreased in the leak with diffusion stage. In the convective diffusion stage, the concentration of each point and the concentration difference of points decreased due to the convection of supply air. Overall, the leaked refrigerant gathered near the floor in vertical direction and there is an obvious concentration attenuation horizontally. The concentration of point6, which was near the leak hole, is higher than the LFL of R32. Concentration of R32 near the floor and the mainstream zone of the air supply is only about 20% of the LFL. Therefore, the indoor environment is safe relatively.

3.3 Ignition Experiment

From all above, it can be found that only the concentration of point6 exceeds the LFL when the air velocity and angle was keeping at 5.8m/s and 25° respectively. In order to evaluate the security of indoor environment, electric and candle fire source were placed near point6 to take the ignition experiments. The results are shown in Fig. 7. and Fig. 8. Fig. 7. shows the infrared picture of the spark near point 6 per 25s. It can be found that the spark begins to diffuse at 75s after starting and shrink at150s after starting. The area the spark diffused is limited to a small space. Compare the two candles in Fig. 8, it can be found there is a certain diffusion of the flame in point 6, but the spread area is very small. It is because that the concentration distribution of R32 is not uniform in the space. The flame can only be ignited in combustible zone, but cannot spread effectively. Therefore, fire hazard will not happen when R32 leaks from a running air conditioner.

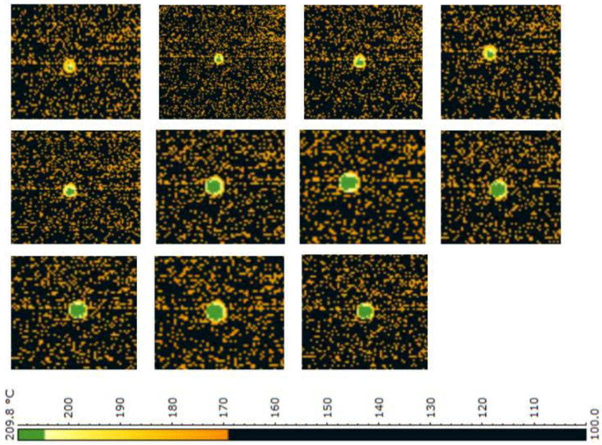

Fig. 7. Variation of spark

Fig. 8. Variation of candle flame

3.4 The Impact of Exhaust on Indoor Security

From above, it can be found that the combustible zone appeared near the leak hole when the leak occurred at the outlet of the evaporator with the conditioner running. In order to improve the security of indoor environment, this paper analyzed the impact of exhaust on the concentration variation. In experiment, open the exhaust fan when the refrigerant and indoor air are fully mixed. Fig. 9.shows the concentration variation of each point with the exhaust fan running. The result shows that the concentration of each point decreased rapidly and tended to 0. And the process can be divided into two stages, rapid decline and slow decline stage. The decline rates were about 0.033vol%/min and 0.001vol%/min, respectively. In the rapidly decline stage, the concentration decreased 90% in 20mins after exhaust opened and it was only about 0.05% of the LFL. From above, it can be concluded that exhaust can effectively reduce the concentration and improve the security of indoor environment.

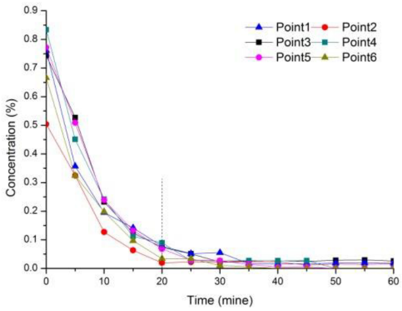

Fig. 9. Concentration variation of each points with the exhaust fan on

4. Conclusions

This paper explored the variation of R32 leak and diffusion with the air velocity and angle keeping at 5.8m/s and 25°, using experimental methods. The security of indoor environment and the effect of exhaust on it were analyzed. From all above, the following conclusions can be concluded:

(1) The refrigerant leak rate decreases gradually with the air conditioner operating. And the process can be classified into two stages, fast leak stage and slow leak stage, and the leak rates are 71.1g/min and 6.52g/min, respectively.

(2) The concentration variation trend of the points are the same. It increased first, then decreased in leak with diffusion stage. In convective diffusion stage, the concentration of each point and the concentration difference of different points decreased due to the convection of supply air.

(3) Overall, the leaked refrigerant gathers near the floor in vertical direction and the concentration has an obvious attenuation horizontally. The concentration of point6, which is near the leak hole, is higher than the LFL of R32. The concentration of point1 to point5 were no more than the LFL. Therefore, the indoor environment is safe relatively.

(4) Ignition experiment was taken in a combustible zone and the results showed that the spark and candle flame diffused slightly, but it cannot spread effectively. Therefore, fire hazard will not happen when R32 leaks from a running air conditioner.

(5) The concentration variation with the exhaust fan on can be divided into two stages, rapidly decline and slowly decline stage. In rapidly decline stage, 20mins after exhaust opened, the refrigerant concentration decreased 90%. Therefore exhaust can effectively reduce the refrigerant concentration and the risk of fire indoor.

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