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Review Article

Analysis of gas diffusion in closed space: A Review

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Abstract

The hydro-chloro-fluorocarbon (HCFC) and hydro- fluorocarbon (HFC) are common refrigerant used for room air conditioner (RAC). But these are restricted due to a serious environmental issues owing to the high global warming potential (GPW). The replacement with low-GPW refrigerant such as R1234yf, R1234ze, R290 and R32 can be possible. R290 (propane) has major environmental and thermo-physical properties. But it is a flammable substance, thereby posing additional risks. When refrigerant leak into space, it may ignite if the concentration is higher than low flammable limit (LFL), there is always a region where the refrigerant concentration is higher than the LFL because the refrigerant concentration is 100% near the outlet from the air conditioner. Thus, understanding the refrigerant diffusion phenomena of low-GWP refrigerants is important to acquiring sufficient information for developing safety standards to assess the risks of using these refrigerants. In this study, diffusion phenomena were analyzed when a refrigerant leaked slowly from a room air conditioner (RAC) into a closed space.

Keywords: *Air conditioner, R290, Flammability.*

1. Introduction

Refrigeration, including air conditioning is necessary for life and will continue to expand worldwide. The emission of CFC, HCFC and HFC in to atmosphere contributes 1-2% of greenhouse gases emission. The Kyoto protocol was signed in 1997 on global warming and climate change. According to it greenhouse gases should be replace with low -global potential refrigerant such as R32, R29, and R152. But these low global potential refrigerant are often flammable.

In order to reduce the risk of refrigerant flammability, it is important to obtain the information about leakage of flammable refrigerant. Past several reports indicate that, when flammable refrigerant leak in to the space, if they are heavier than air then they tend to accumulate above the floor. And refrigerant may ignite 1) when the refrigerant concentration is greater than the LFL, 2) if there is any ignition source and 3) if air velocity is lower than the burning velocity. Propane R290 is the important refrigerant to consider, since it have the most attractive thermo physical properties for air conditioning. When flammable refrigerant leaks in to a room and stagnates near the floor, it can be ignited, resulting in a fire or explosion. It seems to be most critical potential hazard arising from the use of flammable refrigerant. Thus, appropriate safety standards must be prepared for air conditioning equipment containing flammable refrigerant. The study of refrigerant diffusion phenomena is important to preparing safety standards. In this study, diffusion phenomena when refrigerant leaks into a large space from room air conditioner were analyzed. The refrigerant concentration distribution results were verified by using the refrigerant leakage experiment.

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Table 1: Thermodynamic properties of some potential low GWP alternatives

Refrigerant properties	HCFC-22	HC-290	HFC-161	HFC-32	HC-1270
Molecular weight	86.5	44.1	48.06	52	42.1
Normal boiling point (◦C)	-41.0	-42.0	-37.6	-52	-48
Critical temperature, (◦C)	96.20	96.70	102.15	78.1	91.06
Critical pressure, MPa	4.99	4.24	5.09	5.78	4.55
GWP	1780	5	4	704	1.8

2. Literature review

Recently a lot of researches are carried out on gas diffusion and fire hazard.

D.colbourne, K.O.Suen (2003) tested experiments on the dispersion of carbon dioxide which leaked in closed space. In this study carbon dioxide concentration and flow visualization, due to the parameters such as equipment airflow and installation height observed.

Osami Kataoka (2005) studied allowable charge calculations for flammable refrigerant to minimize flammability risk. Different parameters affect refrigerant dispersion behavior such as concentration increase with increase in leak rate, if the leak duration is shorter increases concentration on floor.

Zhang (2010) evaluated the performance of HC-290 in split ACs with various capillary dimensions and configurations.HC-290 gave better performance for parallel capillaries with larger diameters than single capillarywithsmallerdiameters.HC290gave8.5%higher EERAC and4.7% to 6.7% lower cooling capacities compared to HCFC-22.

Wang Zhang, Zhao Yang (2013). R-290 is a flammable refrigerant. For this ignition hazards of an air conditioner are evaluated using R-290. This research was done on distribution of R-290 in a room, Ignition test after the leak process of R290, and ignition test during leak process of R290. From this research it was found that flame can be occur after leakage of R290 is found within the close of indoor unit. It means that only source of ignition present in immediate proximity of indoor unit. And at this area have the possibility to ignite a leak of refrigerant.

Ryuichi S. Nagaosa (2013) evaluate a new numerical formulation for gas leakage and spread into a residential closed space. In this study a computational fluid dynamics (CFD) technique is used to calculate the three-dimensional details of the gas spread with resolving all the essential scale. In this examination of effect of gas density on the concentration profiles of flammable gas spread were studied.

Hiroaki Okamoto and Tatsuhito Hattori (2014) presented the refrigerant concentration distribution with the volume, flammable region and their change over time. They analyzed the risk of ignition on the Leakage of refrigerant. The cases were considered such as a wall mounted indoor unit, a floor mounted indoor unit, leakage from outdoor unit. It was found that concentration does not reach up to the lower flammable limit (LFL) when leakage from a (wall-mounted) indoor unit and it exceeds the upper flammable limit (UFL) when leakage was from indoor unit (floor mounted.)

3. Study of leakage concentration

The evaluation was done in a test room which dimensions were 4.8 m × 3.6 m with stature 2.6 m; this sizes of room generally preferred as a typical master bedroom. The casing of the test room is a light-weight steel rooftop and dividers of calcium silicate board which are painted from inside. A entry way and a window were introduced and no furniture was set in the room.

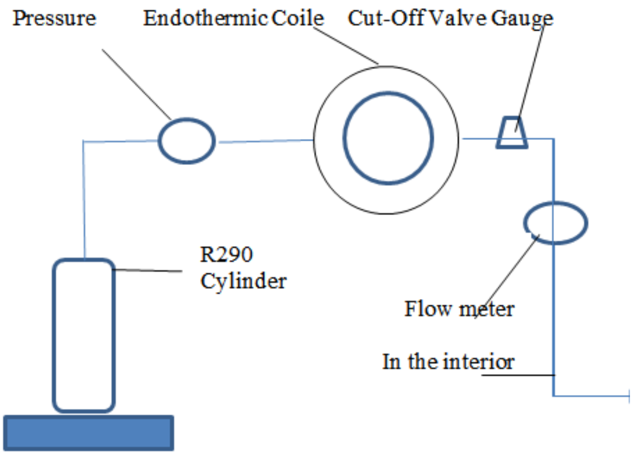

Fig 1 Gas supply system arrangement for diffusion test

To study the leakages from the indoor unit, a cylinder containing R-290 was placed with a pipe into the indoor unit, the installation of indoor unit was at height 2.2m. from ground floor. Refrigerant mass for a given room area can be calculate according to the following equation

$$m_{\max} = 2.5(LFL)^{5/4} h\sqrt{A}$$

Maximum allowable charge for the room size 4.8m × 3.6m×2.6m is 382g, therefor the leakage mass considered as 382 g.

A leakage timing of around 4 minutes is considered because it was rapid. Therefor to represent the most dangerous situation, the discharge span of 3 min, 4 min and 7 min for the 382 g of R-290 were chosen. The indoor unit evaporator and the refrigerant pipe connector at the back of the indoor unit are the most common two point focuses. These were selected as the two leak positions for analyzing the different leak rates.

12concentration sensors are used. The concentration sensor used for testing are an infrared point flammable hydrocarbon gas detector. With range is 0 to 2.1 %. The past study shows that 2.1 %is the LFL of R-290 with an output of 4 ~20 mA. Among from twelve sensors six sensors as numbering (C3, C6, C9, C10, C11, and C12) were positioned at the floor (0.2 m). Three (C2, C5, C8) at 0.8 m height, and three (C1, C4, C7) at 1.5 m height from floor.

CFD analysis numerical procedure

CFD technique is implemented for the unsteady three dimensional to evaluate the concentration profile. Considering the leak gas is incompressible Newtonian fluid, the governing equations are as follows,

$$\frac{\partial U_i}{\partial x_i} = 0$$

$$\frac{\partial U_i}{\partial t} = \frac{\partial}{\partial x_i}\left(\nu \frac{\partial u_i}{\partial x_i} - U_j U_i\right) - \frac{\partial}{\partial x_i}\left(\frac{p}{\rho_0}\right) + \left\{\frac{M_0(r-1)}{\rho_0} C + \beta T_0\left(1 - \frac{T}{T_0}\right)\right\} g_i$$

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x_i}\left(\frac{\nu}{Sc}\frac{\partial c}{\partial x_i} - U_j C\right)$$

$$\frac{\partial T}{\partial t} - \frac{\partial}{\partial x_j}\left(\frac{\nu}{\Pr}\frac{\partial T}{\partial x_j} - U_j r\right)$$

U= Velocity (m/s)
P= Pressure (Pa)
C=Concentration mole/m3
g = Gravitational acceleration (m/s2)
β = Volume expansion coefficient (1/T0)
r = Density ratio between the leaked gas air
Sc = Schmidt number (ν/D)
Pr = Prandtl number
Subscripts (i, j,) in equations are for designate the x, y, and z directions.

The governing equations are solved by utilizing an open source CFD package. The CFD package applies the PISO (Pressure implicit splitting operator) algorithm to solve these governing equations.

3.2. Results of concentration study

The refrigerant was released from both evaporator and connector positions as per consideration, and the concentrations measured at various locations within the room. Results of concentration experiment.

3.2.1 Results of leakage from evaporator

Table 2- Experimental result of evaporator leak

No.	Mass of leakage(g)	Leakage time(s)	Maximum concentration (%)	sensor
1	382	172	>2.1	C1
2	380	186	>2.1	C1
3	382	180	1.8	C1
4	382	243	>2.1	C1
5	382	428	1.79	C1
6	385	420	1.21	C6
7	382	183	>2.1	C1
8	390	247	1.17	C3
9	382	249	1.29	C1

As the refrigerant leaks from the evaporator, 6 minutes and 20 second were taken by the refrigerant R-290 to distribute and concentrate. When leakage was taken from the evaporator, it was found that R-290 was directly discredited onto the sensor C1. Therefor the concentration at C1 exceeded the LFL of R-290. The maximum concentration of sensor C2 and C3 which are at height 0.8 was about 0.5 %. No any other sensors concentration reach up to the lower flammable limit.

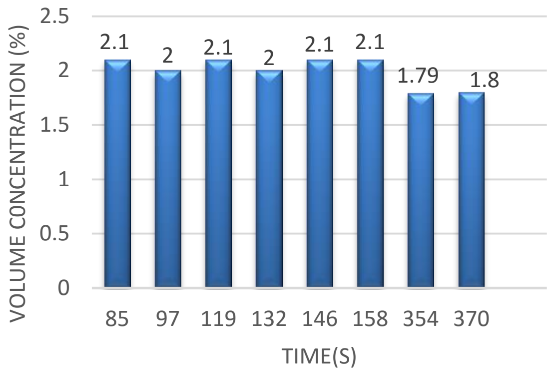

Fig.3 Volume concentration at sensor

C13.2.2Results of leakage from the connector

The refrigerant pipe connector required to be installed nearby, this joining point tends to be one of the parts most chances to leakage. A series of test were conducted on the leakage from the connector. Concentrations emerging from leakage from the connector. The refrigerant was discharged more than 5 minutes 27 seconds. But during this analysis no any sensor's concentration reach to the lower flammable limit.

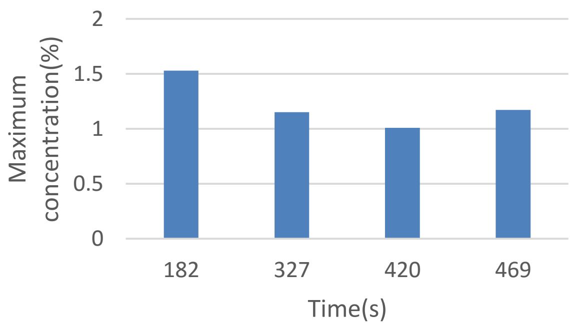

Fig4 Maximum concentration at sensor C3

4. Study of diffusion phenomena with changes in positions of RAC unit

For this study position of the indoor unit can be as follows

1) Wall mounted indoor RAC unit

If the indoor unit is located at definite height above the floor then the leakage rate can be analyze using sensors. For this considering a closed space with dimensions of 2.8 m × 2.5 m × 2.4 m. The indoor unit was located 1.8 m above the floor at the center of one of the walls. The refrigerant was leaking from a wall-mounted indoor RAC unit.

2) Floor-mounted Indoor RAC Unit

In case of floor mounted unit is placed at floor at the center of one wall. Consider the room volume is 2.8 m × 2.5 m × 2.4 m.[1] test were carried out when refrigerant was leaking from the floor mounted unit observation are for this test.

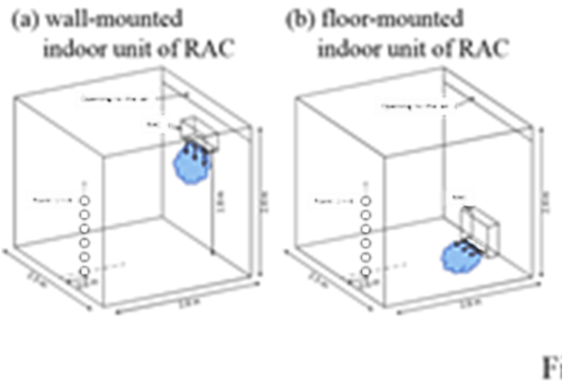

Fig5 Position of wall mounted & floor mounted indoor unit

3) Outdoor RAC Unit

If the outdoor unit was placed on the floor out of the rom. And Refrigerant is leaking from fan of outdoor unit. For this condition consider unit placed on a balcony with dimensions of 5.0 m × 1.2 m × 1.1 m.

4) Variable Refrigerant Flow unit

Considering Refrigerant is leaking from air outlet and suction. The indoor unit of the VRF was located on the ceiling at the center of the office. This indoor unit had an air outlet with dimensions of 0.45 m × 0.0645 m and a suction opening that was 0.37 m in diameter.

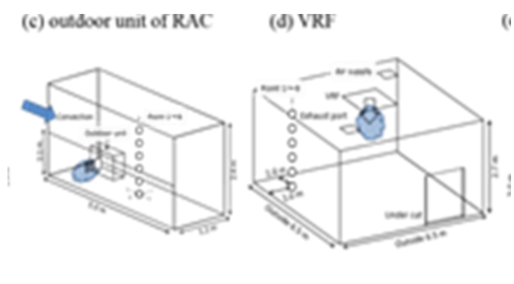

Fig6 Outdoor RAC unit and VRF unit

Table 3 Calculation results.

Test No.	Presence time (min)	$\sum(V_F.t)$ m.min	$\sum(V_{BVFL}.t)$ m.min
1	4.01	0.0118	0
2	4.01	0.0123	0
3	8.01	0.00979	0
4	8.01	0.0107	0
5	1.03	0.0373	0
6	1.05	0.0434	0
7	4.73	0.258	0.161
8	1473.0	7689	7688
9	111.00	136.83	136.81
10	309.4	507.82	507.5
11	45.0	43.01	42.5
12	93.0	62.54	61.53
13	157.85	1.622	0.021
14	157.85	0.831	0.011
15	157.82	0702	0.014

Σ(V·t) = flammable gas volume present time (m^3se)

VFL =flammable gas volume,

VBVFL = flammable gas volume when an air velocity is lower than the burning velocity.

Conclusion

Number of analyses were carried out when indoor unit was wall mounted with height at 2.2m from floor. the results are listed in Table 2. It can be seen from summery that only in four test was the concentrated. (at sensor C1).i.e. at this sensor only leakage rate exceed the lower flammable limit. And this occurs for the evaporator leak only (fig4). When the point of Leakage is connector, the concentration at any sensors did not reach to lower flammable limit (Fig 4). The flammable range of a release of R-290 is just situated inside the nearby region of the indoor unit, shows that that ignition can be occured immediate vicinity of the indoor unit have a likelihood to ignite a leak of refrigerant.

On account of leakage from indoor unit(indoor unit), ignition does not occur, regardless of possibility that a start source exits, it is due to only convection caused by the refrigerant leakage. Therefore, no burning occurs if no any ignition source exists inside the indoor unit.

In case floor mounted indoor unit both the terms $\Sigma(V_{FL}\cdot t)$ and $\Sigma(V_{BVFL}\cdot t)$ comparative. These results suggest when the air velocity if lower than burning velocity ignition can be possible. That means if any start source exists in that region, there is a risk of combustion. Safety regulations are required when flammable refrigerants are utilized in air cooling systems.

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