CFD Analysis of Refrigerant Diffusion Inside Room

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Abstract

This paper describes the simulations for two test conditions. Empty room simulation and other one for to decide the quantity of ventilation requirements needed to moderate the risk of flammability when leakage is present of refrigerants from large chillers inside rooms. Room size is 376 m^3 is simulated using computational fluid dynamics. The chiller capacity is 2640 kW. Cooling solutions is carbon dioxide (CO_2) natural refrigerant (R744) for machine room and for empty room R-290. The paper presents the required safety standards, and refrigerant concentration sensor is involved to activate ventilation system for an emergency to dilute the refrigerant concentration with fresh air. The results of the simulation data established ventilation standards needed for moderate the risks of refrigerant leakage inside given rooms.

Keywords: *CFD analysis, R-290, empty room, machine room, ventilation*

1. Introduction

Long-term service of Freon refrigerants in heating, ventilation and air conditioning (HVAC) systems has a series impact on environment, such as series impair to the global ozone layer. lately Freon refrigerants are being phased out in HVAC industry, while come up with flammable materials such as propane and R32, R717 are selected .In such case, the safety management of those flammable refrigerants needs to be concern, especially the refrigerant leakage due to pipeline corrosion and sealing materials aging etc. When assessing the flammability aspects of refrigerants, the general areas of interest are flammability characteristics, leakage characteristics, dispersion behavior of leaked refrigerant, potential sources of ignition, consequences of ignition including formation of decomposition products and the combination of these within overall risk assessment. The lower flammability limit (LFL) with computational fluid dynamics (CFD) simulation. Mixtures of diffusive combustible materials and air will burn only if the mixture concentration lies within lower and upper bounds which are calculated experimentally and known to as flammability limits or explosive limits. Normally limits are expressed in terms of volume. The LFL is lower end of concentration limit over which a flame mixture of gas in air can be ignited at given temperature and pressure Outside this range of air/vapor mixtures, the mixture cannot be ignited (unless the temperature and pressure are increased). The LFL decreases with increasing temperature.

Leaks can be caused by many problems including unit vibration, physical damage, stress, worn service valves, etc. leak causes ice to form on the coil and other parts of the air conditioner.

From last ten years, several dispersion models have been modeled for flow and diffusion of flammable refrigerant, which consist density greater than air. Most of the toxic and flammable materials involved in leakage accidents are heavy gases (Markiewicz, 2012; Sun et al. 2013). The computational fluid dynamics (CFD) is the most efficient model because it can trace the effect of obstacles on gas flow and diffusion, although it consumes more computation time (Tauseef et al., 2011). The risk analysis of leaked flammable refrigerants into a without ventilation three-dimensional space. The Concentration of a flammable refrigerant leaked at a leakage window, Cin, can determined by mass balance, Limits refrigerant mass for a given room area according to the following formula.

$$M_{max} = 2.5 LFL^{5/4} h_o A^{1/2}$$

The limit mass depend on the different room and room air conditioner height. (Ryuichi Nagaosa et al.,2012). The effect of the leak rate, wind speed, and obstacles for indoor space and gas was carbon dioxide using the FLUENT model. It is found that the possibility of refrigerant concentration within the range of LFL and

UFL is limited only area very close to the leakage point. (Wang et al. 2013).

2. CFD Modeling

2.1. Room description and dimensions

The room dimensions were: 4.87 × 3.65 × 2.95 m (L × W × H) and a floor area of 17.8 m2. The entrance to the room is a 0.7 m 2.0 m door. Two conditions were tested

1) The room was empty and the door and windows were kept closed for the test duration.

2) The room was with chillers and ducts and other intake and exits of air ventilated are shown as in fig.2. The exhaust ducts for ventilations are with 762 mm square opening. These are located are shown as in fig.2. And three fresh air intake openings (762 × 762 mm) are located directly opposite wall. The height is 305 mm above the floor. The stream of fresh air was continuously been swept across the chillers.

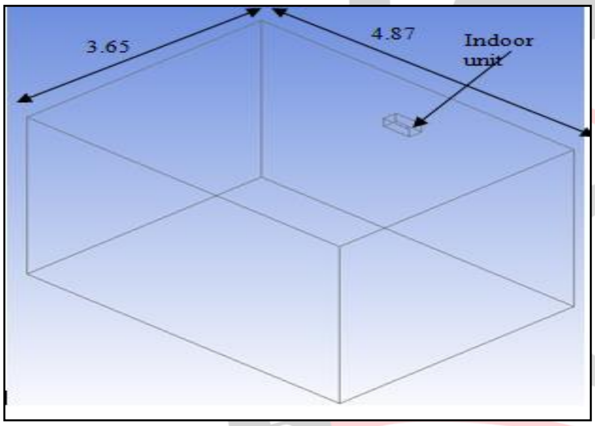

Fig.1 *Model of empty room*

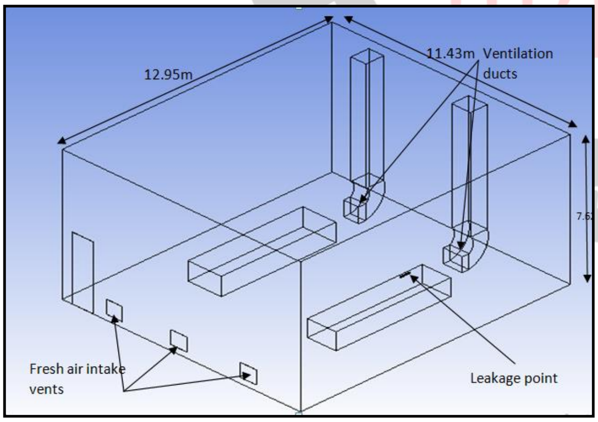

Fig.2 *Machine room configuration*

2.2. Test procedures

A total leak time is 4 min. Other conditions implicit in the formula include the direction of the release being downwards and the refrigerant leak being in vapour phase. The corresponding leak rate would be 0.0016kg/sec. The test procedures were carried out according to the following conditions:

Table 1 Experimental parameters

No.	Leaking rate		RAC condition		Leak Direction	
	High	Low	Working	Non working	Horizontal Axis	Vertical Axis
1	○		○		○	
2	○		○			○
3	○			○	○	
4	○			○		○
5		○	○		○	
6		○	○			○
7		○		○	○	
8		○		○		○

2.2. Boundary conditions and solving setup

The models selected for diffusion is species transport with thermal diffusion. Four different RANS-type turbulence models were available for the simulations of heavy gas dispersion in a large indoor environment. K-ω with SST is selected. A mass flow inlet boundary was imposed on the release source. Leakage refrigerant and air inlet temperature are also introduce as respective inlet boundary condition. The leak hole size is 0.0019m. The exhaust ducts were outlets with pressure outlet boundary conditions. A exhaust fan model used inside the ducts to give the boundary condition of the pressure variation. The rest of the boundary (including the surfaces of the ground, obstacle, and side walls) was defined as impermeable no-slip walls. The governing equations were solved using the PISO algorithm, and the spatial discretization method adopted a second-order upwind scheme.

2.3. Relationship for ventilation rate and sustained leaks

It is possible to write the relation between air ventilation rate and dilution the concentration for exceeding maximum concentration limit cases. For given case prevention on concentration of flammable refrigerant mass in room using perfect ventilation system is important. Maximum acceptable concentration level can be consider ξ*LFL, where ξ is a fraction of concentration safety factor. If it is assume that room is a well-mixed room, the ventilation rate (volumetric) required to dilute the concentration can be written as

$$Q_a = \frac{m_l}{\xi LFL}$$

Where

m_l =the refrigerant leak mass flow rate

$$m_l = \frac{p_o A}{\sqrt{T_o}} \sqrt{\frac{\gamma}{R}\left(\frac{\gamma+1}{2}\right)^{\frac{-\gamma+1}{2(\gamma-1)}}}$$

3. CFD results and discussion

This study evaluates the concentration profiles of the leaked gases in the y direction at nine sampling points from.

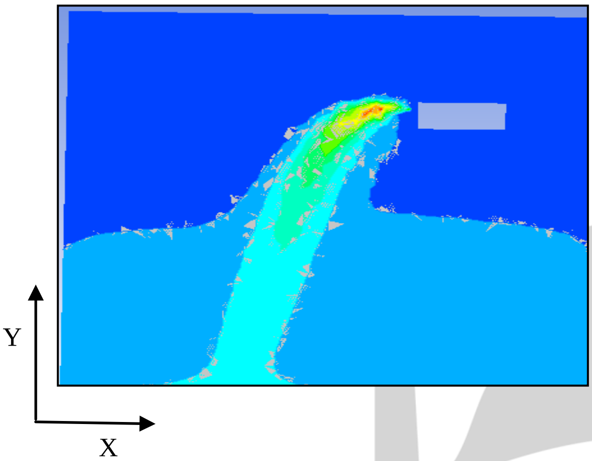

Fig.3 Concentrations Developed from an Evaporator Leak of R290 from an indoor unit for test 1 (horizontal leakage) condition.

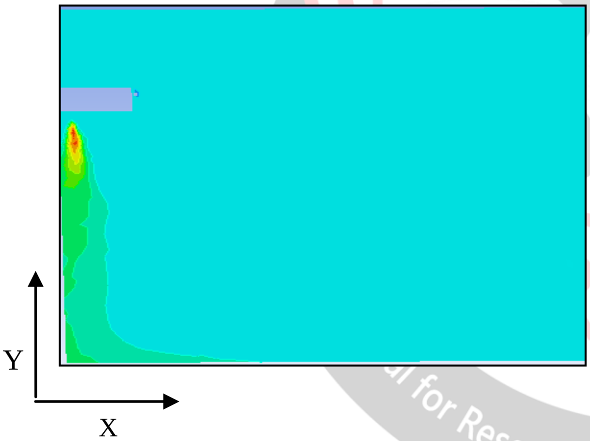

Fig.4 Concentrations Developed from an Evaporator Leak of R290 from an indoor unit for test 2 (vertical leakage) conditions.

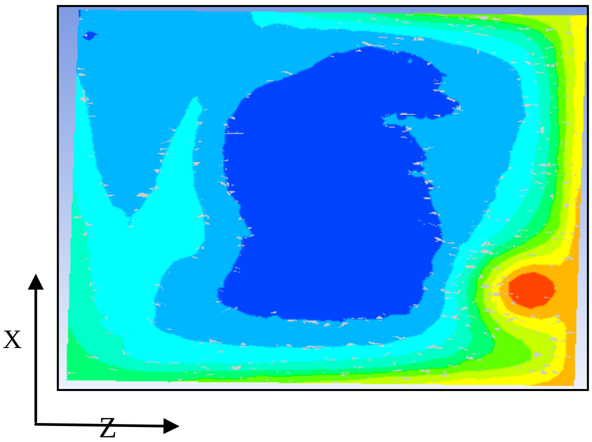

Fig.5 Concentrations Developed from Leak of R290 from an indoor unit for test 3 (horizontal condition

Table 2 Test results for empty room

No.	Leaked mass (g)	Leaking time (s)	Highest point concentration (kg/m³)	Distance from leak point (m)	Highest average floor concentration (kg/m³)
1	0.384	240	0.02175	1.12	0.01957
2	0.384	240	0.0126	0.15	0.01044
3	0.384	240	0.0370	1.8	0.0255
4	0.384	240	0.0132	0.05	0.01131
5	0.0504	240	1.93	0.07	1.08
6	0.0504	240	1.14	0.05	1.36

Influence of leak rate

Comparing the test No. 1 against 5 , having a leak from the return tube it is found that the leak rate strongly influences the maximum concentration. With a high leak rate, R-290 does disperse as quickly as with the low leak rate. The higher leak rate results in a higher maximum concentration and less uniform distribution inside the room.

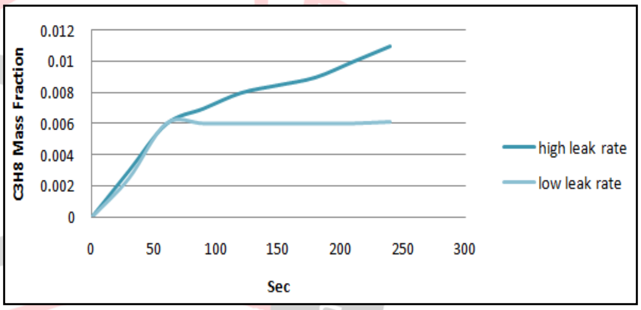

Fig.6 Result for Influence of leak rate

Influence of the leakage flow direction

Comparing the test No.1 against No.2, having a leak in horizontal and vertical gap, it is found that from graph horizontal leakage have strongly influences the maximum concentration.

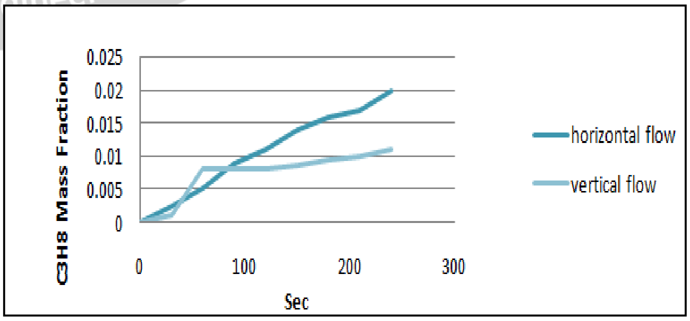

Fig.7 Result for Influence of leak flow direction

The figures of the refrigerant concentration are at horizontal plane in mole fraction taken simulated for leak rates 5, 10, and 40 kg/min when leakage time was 480s. The location of mass accumulation is relatively low as refrigerant is heavier than air. Therefore visualization near floor is the best representation. As LFL of R1234ze is 6.0 vol. This figure cleared that the normal given ventilation rate $101m^3$/min would prevent cloud of refrigerant above LFL level for leak rate 5 kg/min and 10 kg/min in regions outside the chiller.

5Kg/min $101m^3$/min 10Kg/min $101m^3$/min

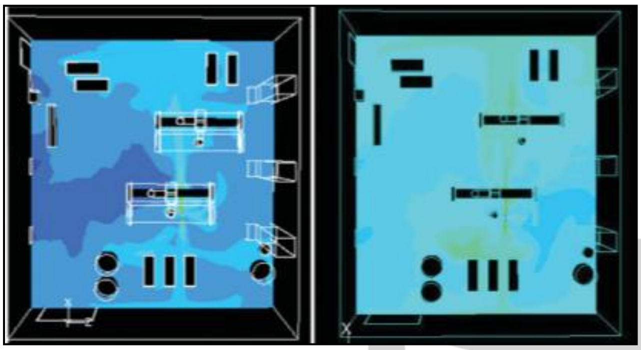

Fig.8 Concentrations Developed on floor from Leak from chiller for 5Kg/min and 10Kg/min.(top view)

For a higher leak rate i.e 40kg/min and ventilation rate is $101m^3$/min, (Figure 9) simulation of refrigerant concentration area which exceed the LFL.

40Kg/min $101m^3$/min 40Kg/min $566m^3$/min

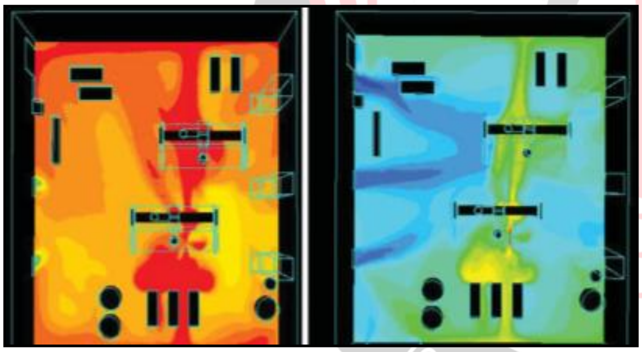

Fig.9 Concentrations Developed on floor from Leak from chiller for 40Kg/min.(top view)

The fig 8,9 shows the total refrigerant mass in the room as a function of time for all the simulations. The total mass (kg) is mass in entire machine room. For refrigerant R1234ze the flammable cloud get form when concentration is between (6vol%-13

vol%). And correspond to this limit cloud can form around leak source. Consequently, ventilation dictates continuous variation of concentration due to significant leakage.

For the 101 m3/min ventilation rate moderate the flammable mass accumulation less than0.001kg for 5–10kg/min leak rates, but the 40 kg/min leak rate results in a continual increase in the flammable mass to more than 30 kg after an 11 min leak time. The ventilation mitigation requirements for the catastrophic 40 kg/min leak rate, an elevated ventilation rate of 566 m3/min were evaluated.

The results show that the ventilation air flow has a large effect on the FVT, similar to results. For example, the effects of enough air ventilation volume this is because the ventilation air makes the refrigerant flow through the exhaust duct to the outlet. This result may be attributed to the enough air ventilation volume. On the other hand, for the non-ventilation case However, if there is no ventilation air flow and there is a high-concentration region after the refrigerant leaks out completely, The results for the leakage from the chiller indicate that sufficient ventilation air flow is needed to keep the room safe when flammable refrigerants are used in chillers. A leakage sensor is also required.

Conclusion

At floor level, the concentration within the room cannot reach the LFL. The concentration only approaches or exceeds the LFL is in an extremely localized region directly underneath the leak position.

Potential ignition sources, such as switches and electrical appliances tend to be located at or near the floor, but very seldom directly below indoor units.

The leak rate has a major influence on the refrigerant concentration distribution. The location of the leak position has a lesser effect. A higher leak rate results in a higher concentration and the easier it is to approach the LFL.

Concentration distributation of refrigerant is a function of leakage rate and ventilation rate are examined in a typical machine room.

The given study for the machine room, that the current ventilation rate specification of 101m3/min would reduce the enhancement of refrigerant concentration levels of above LFL for leak rate 5 and 10 kg/min in regions outside the chiller. The leak rate up to 10kg/min can be diluted with help of ventilation for the largest system charge. But for high leak rate it is not possible for the same ventilation rate to dilute the concentration. The alarm ventilation rate has been shown to be capable of dilute the concentration cloud.

Increase in leaking speed changes the time required to reach up to LFL.

The CFD modeling studied how air ventilation required for moderate the concentration. But machine room size is not function of concentration of leaked refrigerant.

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