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Experimental research on the explosion characteristics in the indoor and outdoor units of a split air conditioner using the R290 refrigerant

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A B S T R A C T

Currently, the most common refrigerants used in household split air conditioners are R22 and R410A. Due to environmental concerns, benign options such as R290 (propane) are under consideration as an alternative. However, R290 is flammable, which poses additional fire and explosion risks. The ignition source and location of the leak that may appear within the indoor and outdoor units were analysed. A series of experiments were carried out to better understand the ignition hazard. The explosion characteristics associated with the indoor and outdoor units were studied whereby the overpressure arising from ignition of R290 was measured at different locations. According to the internal volume of indoor and outdoor units, the amount of R290 that should be deposited inside the indoor and the outdoor units is 7 g and 16 g respectively, to form a stoichiometric concentration. The explosion overpressure in the indoor and outdoor units is sufficiently low so as to not damage the air conditioner system. However, if R290 is ignited during the leak, the indoor or outdoor unit will be burned.

Recherche expérimentale des caractéristiques d'explosion des unités intérieures et extérieures d'un conditionneur d'air split fonctionnant au frigorigène R290

Mots clés : Conditionneur d'air ; R290 ; Propane ; Inflammabilité ; Explosion ; Surpression

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1. Introduction

Currently, China is the largest producer of household air-conditioners in the world. The production of air conditioners in 2014 was about 145 million. The refrigerants employed in household split air conditioners are mainly R22 and R410A. However, both refrigerants are characterised by ozone depletion potential or suffer from high global warming potential. Until now R600a has been the most frequently used hydrocarbon refrigerant with more than 95% of market share in many countries (Joybari et al., 2013) in domestic refrigerators. Whilst due to the successful use of R600a in refrigerators, the manufacturers have more confidence for the application of hydrocarbon refrigerants in air conditioners. However, R290 is a flammable substance, which poses additional fire and explosion risk and is the greatest obstacle to the application of R290. The explosion limit range of R290 is 2.1% ~ 9.5% by volume in air and according to ISO 817 (2014), it is classed as an A3 refrigerant.

Several researchers have carried out studies on fire hazard of flammable refrigerants. For example, Colbourne and Suen (2003a, 2003b) carried out experiments to study the dispersion of carbon dioxide to simulate leaked R290 refrigerant. Zhang et al. (2015) studied the explosion pressures of R32 and R290 at different concentrations using a 20 L ball explosive test apparatus, measuring the total heat release, carbon monoxide, and carbon dioxide production in the event of the indoor unit being ignited by an external fire. Gigiel (2004) carried out experiments to test domestic refrigerator with a flammable refrigerant according to the methods specified in the safety Standard IEC/EN 60335-2-24. Colbourne and Espersen (2013) address the flammability risk of hydrocarbon (HC) refrigerants within horizontal type ice cream cabinets (ICC). The maximum overpressure is 6.5 kPa within the compressor compartment. Colbourne and Suen (2015) compare the risk of a split air conditioner and refrigerator using hydrocarbon refrigerants. It is found that the split air conditioner indoor and outdoor units have an overpressure of only up to 4 kPa. Colbourne and Suen (2014) studied the characterisation of flammable refrigerant leak in a small enclosure. Zhang et al. (2013) also evaluated the distribution of R290 in a room after leakage and measured the overpressure arising from ignition of a flammable mixture, the severity of a secondary fire and the total heat release rate in the event of an external fire imposed upon an R290 system. It was found that in the event of ignition the maximum overpressure within the room is about 6.5 kPa. Also if there are no obstructions near the indoor unit, then explosive mixture around the indoor unit (the concentration of R290 exceed 2.1% in the mixture) will quickly disappear after the R290 leak stopped. But the shell of indoor unit and outdoor unit can hinder the diffusion of R290, so the explosion mixture can stay a longer time than the leak in room. We want to know how long the mixture can stay in indoor unit and outdoor unit.

We identified there are two deflagration consequences. One is sustained burning during the R290 leak process. The other is explosion that occurs after the R290 leak stop. The interiors of indoor unit and outdoor unit are partially enclosed spaces and the shell of indoor units and outdoor units can hinder the spread of R290. In the event of ignition within these spaces, it is important to know the severity of the explosive consequence and the residence time of the explosive mixture within the spaces. The effects of ignition of R290 under these circumstances have not previously been investigated in much detail but studied experimentally in this work.

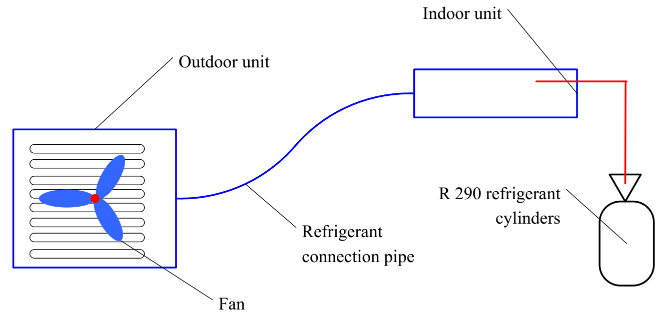

Fig. 1 – Experimental setup.

2. Explosion experimental apparatus and setup

One hazardous situation is where a leak of R290 is ignited and explodes within the indoor unit or outdoor unit. In order to evaluate the consequences of ignition, an experimental rig was constructed and a series of tests were carried out. In the experiments, we chose a split air-conditioner according to the most common characteristics used in households in China. The mass of R 290 charge in model used for the tests was 280 g.

For convenience the indoor unit was installed at the height of 1.5 m in the experimental setup. The outdoor unit was installed at the height of 0.5 m. Outdoor and indoor units were properly connected and before the experiments commenced, the operation of the air conditioner was confirmed. The experimental setup is shown in Figs. 1 and 2.

In the experiment, we used a 2 mm diameter copper capillary tube to feed refrigerant into the interior of the indoor unit. The gas supply system consisted of an electronic balance (accuracy ±0.1 g), R290 cylinder (5 kg, tare weight 2.5 kg), a regulating valve, a pressure gauge, an endothermic (heat absorption) coil, a shut-off valve and a flow meter. The R290 supply equipment was arranged according to Fig. 3 and the flow rate of R290 was adjusted by the flow meter. Once the release amount was achieved, the shut-off valve was closed.

Fig. 2 – Photo of experimental apparatus.