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Comparative evaluation of risk of a split air conditioner and refrigerator using hydrocarbon refrigerants ☆

D. Colbourne [a,*], K.O. Suen [b]

[a] Re-phridge, PO Box 4745, Stratford-upon-Avon CV37 1FE, UK
[b] University College London, Gower Street, London WC1E 6BT, UK

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ABSTRACT

The use of flammable refrigerants, such as R290 (propane), as an alternative to HCFC R22 in room split air conditioners (SACs) is being pursued. Concerns exist that current experience for safe application of R290 SACs is minimal. Conversely, there is extensive application of domestic and small commercial hydrocarbon refrigeration systems; this experience can help determine safety implications to wider use of R290 SACs. This study uses established quantitative risk assessment methods to estimate frequency and severity of ignition of R600a domestic refrigerators, which corresponds to current experience. The methodologies are also applied to R290 SACs based on their particular characteristics to estimate the associated risk. Results show the frequency and severity of ignition of SACs are significantly lower than domestic refrigerators due to the SAC installation characteristics being more conducive for dispersion of leaked refrigerant and less potential for confinement of a flammable mixture in the event of ignition.

Evaluation comparative du risque d'un conditionneur d'air et d'un réfrigérateur split fonctionnant aux frigorigènes hydrocarbures

Mots-clés : Frigorigène hydrocarbure ; R290 ; R600a ; Conditionneur d'air ; Réfrigérateur domestique ; Evaluation de risque

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* *Corresponding author*. Re-phridge, PO Box 4745, Stratford-upon-Avon CV37 1FE, UK. Tel.: +44 1789 268 285.
E-mail address: d.colbourne@re-phridge.co.uk (D. Colbourne).

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1. Introduction

Ozone depleting substances (ODS) such as R22 are being phased out under the Montreal Protocol and other alternatives such as R410A, R407C and R32 which have high global warming potential (GWP) are likely to be restricted also. Therefore strong consideration is being given to the use of hydrocarbon refrigerants such as R290 (propane) and R1270 (propene). For the room split air conditioner (SAC) sector, however, there are concerns that the extent of experience with SACs using flammable refrigerants is small (i.e., several hundred thousand units) despite the potential scale of use in new systems, even considering a small fraction of the global annual production of SACs which approached 120 million in 2013. Having said this, there is extensive experience with hydrocarbons (HCs) in domestic and small commercial refrigeration, where the annual production of R600a domestic refrigerators (DRs) exceeds 80 million. It is well established that HC DRs have an exceptionally good safety record, with a miniscule number of incidents occurring.

Through sources such as manufacturers and international safety committees, the estimated number of incidents up to 2014 has been collated. Using the known population of R600a DRs (over 500 million; UNEP, 2014), the ignition frequency is estimated to be around 1×10^{-9} per year, although it is recognised that the actual number of incidents may be greater by a factor of 2–10 (HSE, 2014). Reasons for ignition were refrigerant leaks migrating into the DR cabinet due to containment faults and then being ignited by the thermostat or lamp switch. The consequences of ignition ranged from sooting found inside the cabinet to the door being blown off across a room (IEC, 2005).

Using quantitative risk assessment (QRA) (which is a probabilistic analysis, systematically evaluating the factors that may lead to ignition and undesirable consequences), the risk of ignition of a R600a DR and a R290 SAC during normal operation is compared on the same basis. This can provide an insight to the potential risk of using HCs in SACs on larger commercial scale and that can also be used to gauge the risk against suitable safe acceptability criteria.

2. Methodology

Since the QRA accounts for the appliance characteristics and environmental conditions that affect the likelihood of ignition, an analysis of the equipment construction, operation and surroundings is required. As described in Colbourne and Suen (2004, 2008) and Colbourne and Espersen (2013), an ignition event is a coincidence of three fundamental events: occurrence of a leak, development of a flammable-refrigerant–air mixture at a specific location, and co-existence of a source of ignition (SOI) being "active" within the flammable mixture. These events have their individual probabilities or frequencies, and the frequency of ignition is essentially the product of these independent events. In summary, the following evaluation comprises the sequential steps of an event tree (e.g., in line with EN 62502, 2011):

- identify each operating mode (system on/off, fan on/off, etc.), external conditions (airflow rates, occupants, sources of ignition, etc.) and probability of each set of combined conditions;
- determine frequency of having certain leak hole sizes and estimate the associated time-averaged mass flow rate of the release;
- for each set of parameters, estimate volume of flammable mixture within control volumes over time (compressor compartment, refrigerated space, indoor unit, outdoor unit, room), see Fig. 1;
- determine the probability of the occurrence of a flammable mixture being present at a particular location within the control volumes;
- nominate a set of potential sources of ignition (SOI) within each control volume, including activation characteristics and their location;
- determine probability of having an active SOIs at the same time as the flammable mixture being present and the corresponding frequency of ignition;
- estimate the corresponding overpressure and thermal intensity, and calculate corresponding risk values.

Further, boundaries for the risk analysis must be clearly defined to ensure the findings are only considered within the intended context; in particular:

- the basic construction of the equipment is based on a common generic design that conforms to the requirements of the relevant standards (IEC 60335-2-24, IEC 60335-2-40);
- the impact of adverse behaviour of room occupants is not considered, for example, manipulation of the refrigerant-containing parts and associated devices is not addressed;
- the individual risk applies to room occupants only and not the broader societal risk, i.e., members of the public or workers in locations other than the occupied room.

The operating environment for the DR and SAC is illustrated in Fig. 1, showing positions of the equipment, examples of potential SOIs and control volumes.

3. Quantification

3.1. Introduction

In order to evaluate the ignition frequency and the risk, the contributing events must be quantified based on data and assumptions using expert knowledge, experiment and/or calculation. In particular, empirical data from field information, measurements and numerical models are used. Whilst determining input values, where there is uncertainty associated with assumptions, the most severe realistic values are chosen, thus representing the most conservative scenarios. Examples include assuming the maximum amount of refrigerant that could leak from the system, ignoring the presence of infiltration, thermal convection and human movement which would ordinarily reduce the size of flammable volumes, and expectation that all leaks occur instantaneously rather than evolving over time. Thus the final outputs of the analysis imply the upper limits of the cumulative uncertainty range.