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Experimental determination of flammability of low GWP mixtures based on alternative refrigerants

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INTRODUCTION

The paper presents an experimental evaluation of the LFL considering the theoretical study of the Heat of Combustion (HOC) of the binary blends based on R152a composed with HFOs and HCs as pre-selected blends that can substitute R410A. Four different blends were tested, the pre-selection of which was based on a numerical analysis of the operation of the refrigeration cycle with an economizer as a method to improve the cooling capacity and the overall efficiency of the system.

Analyzed blends: R1234yf/R152a (0.80/0.20), R152a/R1234ze(E) (0.50/0.50), R290/R152a (0.65/0.35) and R1270/R152a (0.65/0.35).

RESEARCH METHODOLOGY

The LFL determination was performed experimentally in accordance with ASTM E681 - 09 (2015) and ASHRAE Research Project RP - 1717 (Fig. 1). The post-processing of each test run focuses on the visual assessment of flame propagation after ignition. Following the procedure of ISO 817:2014, the sample of the refrigerant mixture is considered flammable if the flame propagates at or above 90° upward and outward from the ignition point until the flame is reflected from the walls of the vessel. The LFL is a calculated value of the average of the lowest flammable and highest non-flammable concentrations.

$$LFL = \frac{C_F + C_{N-F}}{2}$$

The HOC was determined according to ISO 817:2014, including the enthalpy of formation data.

$$HOC = \frac{\sum \Delta H_{f^\circ\, products} - \sum \Delta H_{f^\circ\, reactans}}{\sum_{i=1}^{n} X_i M_i}$$

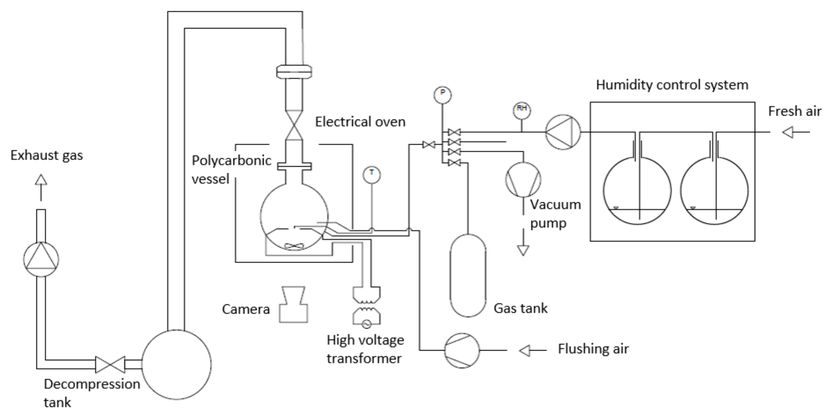

Fig. 1. Scheme of the test setup according to ISO 817:2014 and ASHRAE RP – 1717.

EXPERIMENTAL RESEARCH

Figures 2 and 3 show the least flammable samples in color and monochrome, respectively, as the flame is reflected off the vessel walls.

- **R290/R152a:** R152a does not have much effect on the LFL value as it only shifts the LFL by about 15%. The calculated LFL is 2.52%. The flame is bright blue with a visible orange vertical axis.
- **R1270/R152a:** There is almost no positive effect of R152a on the LFL change, as the blend remains highly flammable, similar to pure R1270. The calculated LFL is 2.55%. The flame color is brighter blue than for the R290/R152a blend, and the orange region was observed only in the early phase of the explosion.
- **R1234yf/R152a:** Adding just 20% R152a reduces the LFL from 6.2% of pure R1234yf to 5.16%, significantly increasing the risk of igniting the blend in the event of a leak. Flame radiation is much more intense, illuminating the interior of the oven.
- **R152a/R1234ze(E):** The addition of R152a changes the value to almost equal to pure R152a. The calculated LFL is 4.89%. The flame is still bright, but not as bright as the blend with R1234yf.

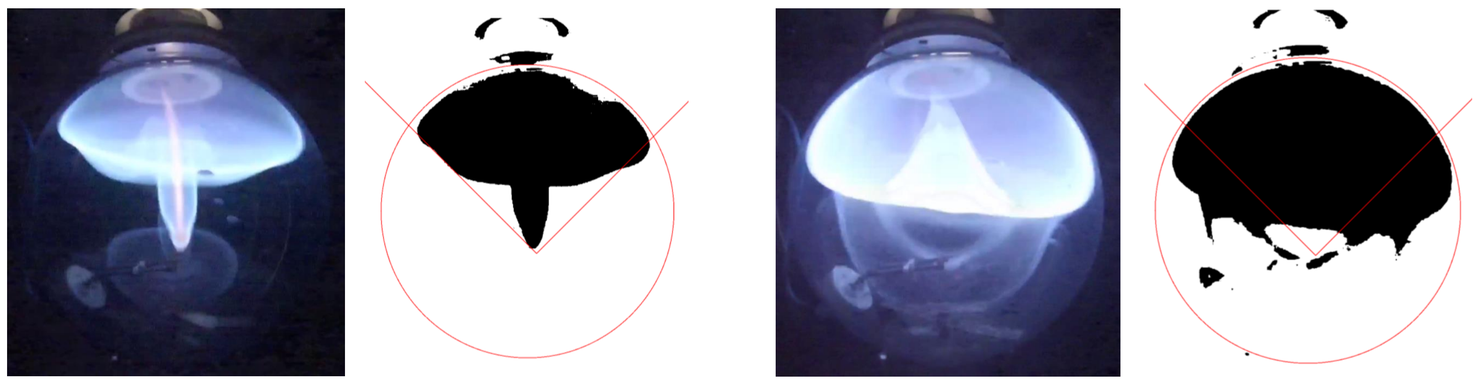

Fig. 2. Explosion of the lowest flammable concentration of R290/R152a (2.52%, 0.046 kg·m^{-3}) and R1270/R152a (2.55%, 0.045 kg·m^{-3}).

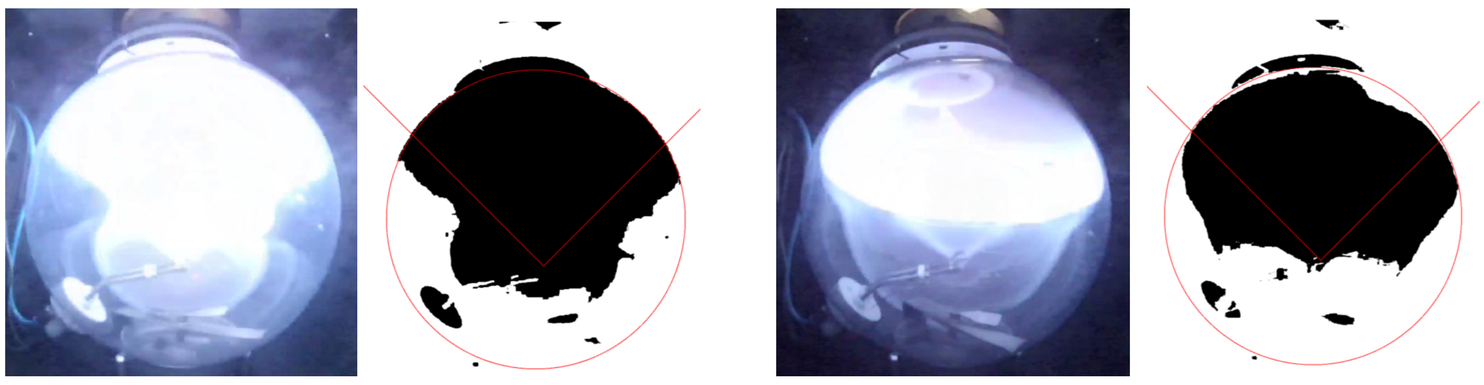

Fig. 3. Explosion of the lowest flammable concentration of R1234yf/R152a (5.23%, 0.191 kg·m^{-3}) and R152a/ R1234ze(E) (4.93%, 0.151 kg·m^{-3}).

CONCLUSIONS

- Hydrocarbon blends show minimal sensitivity to the addition of R152a, with LFL values similar to pure hydrocarbons (neither R290 nor R1270). This may be due to the abundant hydrogen content, which is primarily responsible for the low flammability limit.
- HFO blends are very sensitive to the presence of R152a; even small amounts of R152a significantly reduce the LFL.
- R152a-HFO blends mimic the LFL of pure R152a. The addition of R152a increases the hydrogen in the blend, releasing radical hydrogens that affect process dynamics. Another mechanism is that ignition of the more flammable component rapidly shifts the temperature of the air-gas mixture, making the second component flammable at lower concentrations.
- All of the blends analyzed are in the same flammability class as their R152a-free counterparts.
- The HOC of R290/R152a and R1270/R152a is reduced by approximately 23% compared to pure hydrocarbons (Fig. 4).

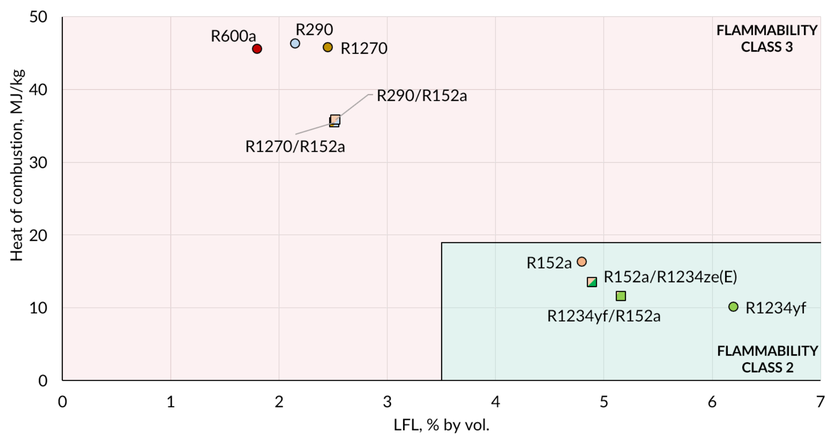

Fig. 4. Flammability classification of blends and pure refrigerants evaluated according to ISO 817-2014.

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